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Cover photograph: *The former Manager's Villa in Stromness, South Georgia, where Ernest Shackleton and companions arrived in May 1916.*

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REVEALING THE DOCUMENTARY EVIDENCE FOR TASMANIA'S RECENT CLIMATE HISTORY PRIOR TO THE COMMENCEMENT OF OFFICIAL METEOROLOGICAL RECORDS IN 1840

by Kathryn Evans

(with two tables)

EVANS, K. 2012 (14:xii) Revealing the documentary evidence for Tasmania's recent climate history prior to the commencement of official meteorological records in 1840. *Papers and Proceedings of the Royal Society of Tasmania* 146: 1–7. ISSN 0080-4703. School of Geography and Environmental Studies, University of Tasmania, Private Bag 78, Hobart, Tasmania 7001, Australia. Email: kathryne@internode.on.net

The establishment of the Rossbank Observatory at Hobart in October 1840 marked the commencement of official weather recording in Tasmania. Little is known of Tasmania's weather history prior to this. A perusal of a range of historical documentary material, including ships' logs, official records, diaries, letters and early meteorological reports can assist in building a picture of Tasmania's weather history in the early years of European settlement, including occurrences of drought, flood, storm and bushfire. Historical sources for the period 1803–1840 are outlined, their uses and limitations discussed, and some of the findings summarised.

Key Words: climate, Tasmania, history, Rossbank Observatory.

INTRODUCTION

Uncovering clues to the weather patterns of the past can inform today's climate science research and help unlock the mysteries of weather events associated with the El Nino Southern Oscillation (ENSO), other causes of climatic variability and climate change. Gergis *et al.* (2010) argue that historical documentary sources are a largely untapped source of information on Australia's recent climate history. They demonstrate how historical documents can be used in conjunction with palaeoclimatology, including tree ring, coral and ice core analysis, to determine the weather conditions experienced in past eras. This paper reviews the historical documentary material available on Tasmania's climate from 1803 to 1840.

A small number of officials and private settlers kept weather records for limited periods in the early years of European settlement in Tasmania. Though patchy and incomplete in nature and though the equipment and methods used to collect and report data are unlikely to meet modern scientific scrutiny, they do provide useful early evidence of the weather conditions that prevailed in the first decades of white settlement. Other, more descriptive, accounts can be gleaned from perusing the official records, diaries, letters and journals of early officials and settlers, or from local newspapers. These give important insights into when droughts, floods and storms occurred, how they affected human settlement, and how land use activity and cultural attitudes could, in turn, alter the risks associated with them. For example, inappropriate land clearing practices often increased the risks to people and property caused by floods (McKay 1962). Such descriptive accounts, however, must also be treated with a degree of caution — they lack the hard "data" demanded from meteorological science today and reflect the authors' own perceptions and biases. For instance, what is perceived as a "drought" may vary from one person to another, depending on their cultural background, location and occupation (Heathcote 1973).

However, with these limitations kept in mind, a variety of historical sources can be used to build a broad picture of Tasmania's climate history from European settlement in 1803 through to1840, including the identification of predominantly wet or dry periods, episodes of severe cold and violent gales and storms.

The documentary records, 1803–1840

Official weather recording began in Tasmania with the establishment of the Rossbank Observatory adjacent to Government House on Hobart's Queen's Domain in 1840. The observatory was the initiative of the British Royal Society (with the assistance of the British Government) and formed part of a network of global observatories. Equipment for the observatory arrived in Hobart aboard the *Erebus* and *Terror* (James Ross, Commander) in August1840, and commencing in October, hourly readings from the equipment, which included a barometer, thermometer and rain gauges, were made under the command of Lt Joseph Henry Kay RN (Bureau of Meteorology 2008). The opening of the Rossbank Observatory initiated a new era in weather recording in Tasmania, thus providing researchers with important historic weather data.

Prior to 1840 a number of officials had taken meteorological readings from time to time. William Paterson kept a meteorological journal at Port Dalrymple in the north for the period November 1804–December 1805, in which readings from a thermometer and descriptions of the prevailing winds, as well as general remarks, were recorded four times a day. Unfortunately, no rainfall measurements were taken, and the entries are generally quite brief (CO 201, reel 25, piece 51). Meteorological journals were also kept by the Commandant Clerk at Macquarie Harbour for a number of years in the late 1820s. It was noted as early as 1839, however, that these journals had been lost (Lempriere 1954 [1839]). Other records were kept by Deputy Assistant Commissariat-General Thomas Lempriere at Port Arthur (1837–1842) and by Joseph Milligan at the Van Diemen's Land Company's Hampshire Hills Estate (1835–1839) (Milligan 1842a, 1842b, 1846, Lempriere 1954 [1836], 1842, 1846). The original Port Arthur records are held at

the Bureau of Meteorology Head Office in Melbourne. They include yearly maximum, minimum and mean recordings from a barometer and thermometers, as well as annual rainfall measurements from July 1837 to December 1842 (Lempriere 1842, 1846).

Milligan's recordings for the Hampshire Hills estate in the far northwest include a table of rainfall for the years 1835–1839, and more detailed descriptions for the years 1835 and 1836, such as the prevailing winds and the number of clear, cloudy, rainy or snowy days and nights (Milligan 1842a, 1842b, 1846). Weekly meteorological tables were also occasionally published in the local newspapers, such as from August 1825 to March 1827 in the *Hobart Town Gazette*, and from January to July 1839 in the *Hobart Town Courier*. These tables give daily maximum and minimum temperatures and comment on whether conditions were fine, cloudy or rainy. Rainfall measurements were not generally provided. Some farmers also kept records relating to the state of the weather. William Pike of "Park Farm" at Jericho recorded in tabular form the number of rainy, snowy or frosty days for each month from 1826 to1840, and occasionally remarked upon severe weather events, such as on 18 January 1828, when "excessive heavy rain was accompanied by the loudest thunder" he had ever heard (RS38/4 1826–1840).

Such statistical data, though very limited in the time periods and geographical areas it covered, are useful in identifying years or periods that were predominantly wet or dry. Data on the number of rainy or fine days or rainfall measurements may provide good indicators as to when droughts, floods or storms occurred. However, on their own they may not give sufficient evidence for this, or for the human impacts of, or responses to, the prevailing weather conditions. For instance, a period of high rainfall indicates that floods were likely, but other sources of information are needed to verify this. It is useful, therefore, to use such weather data in conjunction with other sources, such as descriptive newspaper accounts, diaries or government records that provide more detailed accounts of the prevailing conditions and their impacts on the life of the settlements. Official despatches, as well as accounts, notebooks, letters and diaries of the officers and settlers provide important insights into weather conditions and the general state of the countryside in the early years of European settlement. As settlement spread throughout the island in the 1820s and 1830s the number of sources for determining past weather conditions increases, as does the geographical range that this material covers. In that era there is an increased number of settlers, officials and local newspapers reporting on weather conditions, as well as the surviving records of such companies as the Van Diemen's Land Company (in the northwest) and the Clyde Company (in the Clyde River Valley).

Evidence for early droughts and bushfires

The following is a summary of the historical evidence for droughts and bushfires in the period 1803–1840.

Arriving in the spring of 1803, Lt John Bowen found Risdon Cove a suitable spot for a settlement. The stream at Risdon Cove was flowing and he likened the area to a "Nobleman's Park in England" with every part "beautifully Green" (*Historical Records of Australia* 1921a, p. 198). When Collins' party arrived in February1804, however, it presented a different picture. On alighting from their vessel, the *Ocean*, at Frederick Henry Bay on 11 February, the mineralogist on Collins' expedition, Adolarius Humphrey, and five others set off on foot to Risdon Cove. Humphrey's account points to the dryness of the season: "At ten we began to be very thirsty, as the sun was powerful. The places in which there was fresh water in the rainy season were all dry … I have never suffered so much for want of drink and was almost unable to walk" (Humphrey 1984, p. 91). The log of the *Ocean* reveals that by 17 February Collins had decided that Sullivans Cove on the River Derwent's western shore presented a more suitable place for a settlement, given the inconvenience of landing cargo at Risdon and because the run of water there had "partly dryed [sic] up" (*Historical Records of Australia* 1921a, p. 149). Reverend Robert Knopwood, who was also in Collins' party, recorded in his diary on 18 February 1804 that at the Risdon Cove camp "they have not had a good shower of rain for 4 months" (Nicholls 1977, p. 44). Naturalist Robert Brown, in a letter to Paterson on 4 March 1804, noted that Aboriginal fires had scarred much of the landscape (*Historical Records of Australia* 1921a).

A dearth of water at Risdon continued into the autumn and winter of 1804, as Collins noted in a despatch to Governor King at the end of July:

> *When the small Establishment which was sent to Risdon Cove by Governor King arrived there in September last, they found sufficient fresh Water to deem it a permanent Supply. Upon my arrival, the fresh Water, which, in September was a running Stream, was then confined to a few Pools of dirty standing Water, and … are now little better.* (*Historical Records of Australia* 1921a, p. 247)

The notebooks of convict surveyor James Meehan also indicate that a drought prevailed at this time. During a survey of the Derwent and Jordan rivers in early February 1804 he noted that the country was very dry and that there was a lack of grass on the plains, "the whole of it nearly perished from the Great Drought" (LSD355/3 1804). The summer and autumn of 1805 were also dry in the south (Nicholls 1977).

Surviving records from the first explorations and settlement at Port Dalrymple provide evidence for drought conditions in the north in1804 and the early part of 1805. During an exploratory expedition of the Tamar region, dispatched by David Collins from Port Phillip in January 1804, it was noted by both William Collins and Thomas Clarke that lagoons were then dry and streams reduced. Fresh water was difficult to procure (*Historical Records of Australia* 1921a). By the time their reports were received, David Collins had already decided to relocate his party to the Derwent. When Paterson's party arrived at Port Dalrymple in November 1804 conditions were still predominantly dry. Paterson recorded in January 1805 in a letter to Governor King that "where fresh water is found now there can be no doubt of its being permanent" (*Historical Records of Australia* 1921a, p. 629). He decided to establish a settlement at York Town on the western shore of the Tamar where a running stream had been located. In a further letter in February he noted that the party had experienced very little rain since their arrival (*Historical Records of Australia* 1921a).

Widespread drought conditions also prevailed in the years 1806–1807, particularly in the south. Evidence for this comes from Knopwood's diary entries about the weather experienced at Hobart, such as 5 February 1806: "The day very hot; much in want of rain"; and 8 November 1806: "The weather very dry. Nothing grows for want of rain" (Nicholls 1977, pp. 101, 119). Christmas Day 1806 was

exceedingly hot. The glass in Knopwood's thermometer broke as temperatures soared to 105°F (40.5°C) in the shade (Nicholls 1977). John Pascoe Fawkner, the son of a convict, also recalled that day:

> *Christmas Day this year was the hottest that the writer ever felt there. It was a hot day, and a very windy one; the north wind raged wildly, and towards 10 o'clock A.M. clouds of smoke obscured the sky for miles, and we found that a large extent of the country to windward was on fire.* (Fawkner [c1856] 2007, p. 62)

Exceptionally dry conditions were also experienced in early 1807. Knopwood recorded on 18 February:

> *The day so very hot, scarce able to stir out. We have not had any rain for a very long time. No grass and the country on fire by the natives ... The colony in very great distress for wheat ... and potatoes.* (Nicholls 1977, p. 127)

In March he stated that "the settlement had not had a shower of rain for five months" (Nicholls 1977, p. 129). According to Gergis & Fowler (2009), 1806–1807 were very strong El Nino years. The consequence of drought and a dire shortage of food staples was a heavy reliance by Europeans on the hunting of native game, such as kangaroo and wallaby, to tide the settlements over until a return to more favourable conditions. It also prompted the first overland journey between the two major centres. On 3 February 1807 Lt Laycock embarked on a trip from Port Dalrymple to the Derwent with the aim of procuring relief for the northern settlement. On arriving there on 11 February he found the southern settlement also in dire straits (*Historical Records of Australia* 1921a).

Despite this early suffering by drought, there appears to have been a shift to generally wetter conditions by the 1810s. Evidence for this exists in accounts of floods in 1809, 1812, 1816, 1818 and 1819 (see below). According to Gergis & Fowler (2009) the years 1808–1811 were either very strong or strong La Nina years.

Both southern and northern settlements were on a much firmer footing by 1820. Agricultural and pastoral pursuits were recording greater successes. Nevertheless, drought periodically could still bring matters to a standstill, such as in 1817 (*Historical Records of Australia* 1921b) and 1820 when crops and pasturage for livestock were widely affected (*Hobart Town Gazette* 1821a, *Historical Records of Australia* 1921d, *Hobart Town Gazette* 1821b). A further predominantly dry period extended from the spring of 1823–1825 causing considerable distress (*Historical Records of Australia* 1921d, Nicholls 1977). Governor Arthur wrote to Lord Bathurst regarding the harvest for 1825:

> *From the extraordinary drought of the Season, the harvest was exceedingly deficient, and the consequent want of the means of supporting their Men comfortably led to a good deal of discontent between Settlers and their assigned Servants.* (Historical Records of Australia 1921d, p. 293)

Again, 1827 to the winter of 1828 was very dry to the detriment of farming operations (*Hobart Town Gazette* 1827, *Hobart Town Courier* 1827a, 1827b, 1828a). Hot winds and bushfires in March 1827 made conditions unpleasant:

> *A high northerly wind prevailed on Monday which with the continued drought raised great clouds of dust. Tuesday was close and the fires in the woods on the opposite side of the river added to the sultry state of the air.* (Hobart Town Gazette 1827, p. 4)

It is not clear from this account whether the fires are of Aboriginal or European origin. By this time fires were commonly used by Europeans to clear ground for the planting of crops and to rejuvenate native pasture (Pyne 1991). Lit under the wrong conditions they could quickly escape and become damaging to life and property.

Regional differences in weather conditions were also sometimes apparent. In September 1829 Knopwood recorded that the south of the island was very dry, while in Launceston "they have had so great a quantity of rain that sheep are dying for want of dry food" (Nicholls 1977, p. 543). By January 1830, however, both ends of the island were experiencing drought conditions (Nicholls 1977, *Launceston Advertiser* 1830).

The summer of 1830–1831 to the winter of 1832 proved very dry in both major centres (Nicholls 1977, *Hobart Town Courier* 1832a, 1832b, 1832c, *Launceston Advertiser* 1832a). On 2 May 1832 Knopwood recorded: "we have scarcely had any rain for ten months. The cattle dying for want of food and water" (Nicholls 1977, p. 598). The Hobart Rivulet that provided water for town residents and industry was much reduced, and together with a high level of pollution, brought on numerous health problems (*Hobart Town Courier* 1832a, CSO1/1/230/5605 1831). Rainfall in Hobart for 1831 was 18.26 inches (Jevons 1859).

Spring 1833 to autumn 1836 was another predominantly dry period (punctuated by heavy spring rains in 1834) and led to suffering in many areas. According to pastoralist George Russell of the Bothwell district, the summer of 1833–1834 was the driest that he had experienced in Tasmania for many years (Brown 1935). At Swansea in the east, the pasturage was reportedly "very bare" (*Hobart Town Courier* 1834a, p. 2). Even in the far northwest the Van Diemen's Land Company had a poor harvest due to drought (VDL Co. 1989 [1835]). The dry conditions throughout the colony were accompanied by destructive bushfires:

> *The bush, we are sorry to say, has been either carelessly or maliciously set on fire in all parts of the colony, and done much damage. The neighbours almost everywhere, have been compelled to collect and exert themselves night and day, to repress the progress of the flames and beat them out.* (Hobart Town Courier 1835a, p. 2)

According to the *Tasmanian,* by August 1835 the general drought had dragged on for three years (*Tasmanian and Austral-Asiatic Review* 1835). This drought was finally alleviated by floods in March 1836 (*Hobart Town Courier* 1836a).

The most severe drought for this period, however, was in the late 1830s to the early 1840s. The year 1837 was dry, with heavy frosts experienced in the winter (Nicholls 1977, *Cornwall Chronicle* 1837a, 1837b). Although winter rains were heavy in 1838, by the summer of 1838–1839 dry conditions were again predominant (*Hobart Town Courier* 1838). Phillip Russell of the Clyde Company at Bothwell wrote to his brother George in April 1839 that "there has not been a green leave here for several months" (Brown 1941, p. 212). Their central highland sheep runs were also parched (Brown 1941). In June 1839 the *Hobart Town Advertiser* predicted dire consequences from the paucity of the crops and the high price of food:

> *... throughout the colony the continued drought bids fair to set all human exertion to secure the ensuing crop altogether at defiance. We can scarcely see a hope of anything short of comparative starvation.* (Hobart Town Advertiser 1839, p. 2)

In August the *True Colonist* (1839) reported that potato

crops were deficient, native pastures very bare and stock in poor condition. The east coast was particularly hard hit. The northwest also received less rain than usual, with Milligan recording at the Hampshire Hills the lowest annual rainfall in five years (Milligan1842a). Spring rains alleviated the situation somewhat, but it continued dry in 1840 through to the winter of 1842. On the first year of official recording at the Rossbank Observatory, 1841, the rainfall for Hobart was just 13.95 inches (NS37/1/1 1841, Jevons 1859). The summers of 1838–1839 and 1840–1841 were also marked by destructive fires (*Cornwall Chronicle* 1839, 1841, *Hobart Town Courier* 1841).

Evidence for floods, storms and severe cold

In contrast to the predominantly dry periods summarised in Table 1, at other times heavy rain caused flooding, winters could be very cold with periods of heavy snow or damaging frosts, and storms occasionally wrought damage to buildings, crops and other property.

Despite the dry conditions experienced in the first years of settlement at Risdon Cove, early evidence was also found for past flood events. In Meehan's survey of the western shore of the Derwent in January 1804 he noted that at the Hobart Rivulet there were signs of "moderately high floods". He did not elucidate on when these may have occurred (LSD355/2 1804). On examining the falls on the Derwent (past the current site of New Norfolk) in February he estimated that there had been floods of "about 20 feet high" (LSD355/3 1804).

Paterson's party also found evidence of past floods along the South and North Esk river systems (*Historical Records of Australia* 1921a). By the winter and spring of 1805, the fledgling settlement in the north was experiencing cold conditions that led to mortality among the stock and flooding that damaged low-lying crops (*Historical Records of Australia* 1921a). The susceptibility of York Town to flooding was one of the reasons behind Paterson's decision to remove the settlement to the current site of Launceston in 1806 (*Historical Records of Australia* 1921a). That too, would prove flood-prone.

In the autumn and winter of 1809 both major centres experienced floods – Launceston from the South and North Esk rivers, and Hobart from the overflowing of its main rivulet (*Historical Records of Australia* 1921a, *Hobart Town Gazette* 1816a). Over the years, the Hobart Rivulet would be subject to occasional flash flooding, the effects of which became more damaging as buildings and bridges were built

TABLE 1
Reported droughts in southern Tasmania 1803–1840

Year	Date/s	References
1803	Nov–Dec.	Nicholls 1977:44
1804	Jan– July	*Historical Records of Australia* 1921a:247
1805	Jan–April	Nicholls 1977:81
1806	Jan–March; Nov–Dec	Nicholls 1977:101–103, 119–123
1807	Jan–March	Nicholls 1977:129
1817	Not known	*Historical Records of Australia* 1921c:253
1818	Jan–March	*Historical Records of Australia* 1921b:310
1820	Sept–Dec	*Historical Records of Australia* 1921d: 4, *Hobart Town Gazette* 1821a: 6 January, 1821b: 20 October
1823	Oct–Dec	*Historical Records of Australia* 1921d:527
1824	Oct–Dec	Nicholls 1977:436-438, 461
1825	Most of year	*Historical Records of Australia* 1921d:293
1827	Most of year	Nicholls 1977: 507–509, *Hobart Town Gazette* 1827: 24 March, *Hobart Town Courier* 1827a: 15 December, 1827b: 22 December
1828	Jan–May	Nicholls 1977: 513–515, *Hobart Town Courier* 1828a: 5 January
1829	Sept–Dec	Nicholls 1977:543–546
1830	Jan; Nov–Dec	Nicholls 1977:550, *Hobart Town Courier* 1831a: 12 January
1831	Most of year	Nicholls 1977:598, *Hobart Town Courier* 1831b: 5 November, 1831c: 17 December, Jevons 1859
1832	Jan–May	Nicholls 1977:598, *Hobart Town Courier* 1832c: 7 April
1833	Oct–Dec	Nicholls 1977:621-625
1834	Jan-August	*Hobart Town Courier* 1834a: 6 June, 1834b: 25 July
1835	Most of year	*Cornwall Chronicle* 1835: 18 July, *Tasmanian-Austral Asiatic Review* 1835: 21 August, *Hobart Town Courier* 1835b: 25 September
1837	Most of year	Nicholls 1977:660–666
1839	Most of year	Brown 1941: 212, 288, *True Colonist 1839*: 30 August
1840	Most of year	Brown 1941: 362, 385, *Hobart Town Courier* 1840: 29 May

Drought periods in the table are based on periods of three months or more of below expected rainfall that had negative human consequences, such as suffering to crops, livestock and depleted town water supplies.

up along its banks. After a week of incessant rain in July 1816 the rivulet swelled dramatically causing much anxiety among Hobart residents (*Hobart Town Gazette* 1816a). A repeat flood in September 1819 had destructive consequences:

> *During the day and night of Thursday, and all yesterday, a very heavy gale of wind with incessant rain prevailed. The torrent of water which flowed down the rivulet has done considerable damage. The banks in some places have been undermined and loosened, and some houses have been damaged; and we lament to say that the new brick bridge in Argyle Street, which was nearly completed ... was carried away.* (Hobart Town Gazette 1819a, p. 2)

Inclement weather in the winter and spring seasons of 1818 and 1819 created floods that impeded transport and communications between Hobart and Launceston (*Historical Records of Australia,* 1921b, *Hobart Town Gazette* 1819b, Nicholls 1977). Widespread flooding was also experienced in the spring of 1822 and in the winter and spring seasons of 1826 and 1828. Official plans by Governor Arthur to remove the seat of government to New Norfolk were aborted due to the violence of floods along the Derwent River in 1826 (*Historical Records of Australia*, 1921e).The floods of September1828 damaged bridges, houses, mills and gardens situated along the Hobart Rivulet. An artificial diversion of the rivulet's course, carried out in 1825 to allow land reclamation of the wharf area, substantially increased the impacts on the lower end of town (near today's City Hall) (*Hobart Town Gazette* 1822, McKay 1962, Nicholls 1977, *Hobart Town Courier* 1828b, 1828c, 1828d).

In a particularly wet and cold winter, further damaging floods were experienced along the Hobart Rivulet in late May 1832 (*Hobart Town Courier* 1832d). Northern districts also had inundations in low-lying areas, causing much damage to roads (*Launceston Advertiser* 1832b, 1832c, 1832e), while farmers had difficulty transporting goods to market:

> *The effects of the long continued wet weather ... begins to be felt by the towns' people. Every article of farm produce is becoming scarce and dear, while scarcely a bit of butchers' meat, fit to bring to the table, is to be had.* (Launceston Advertiser 1832e, p. 5)

The operations of the Van Diemen's Land Company were considerably set back when the severe cold and wet caused heavy losses of lambs and sheep in their highland estates (VDL Co. 1989 [1833]).

Further floods were experienced in the south when a long dry spell was suddenly broken in late February and March 1836 (*Hobart Town Courier* 1836a). Floods were also widespread in June 1838, with the New Norfolk district being particularly hard hit (*Hobart Town Courier* 1838). The weather data from the Van Diemen's Land Company's Hampshire Hills estate also attest to heavy rainfall in the northwest in June and July 1838 (Milligan 1842a).

These events are summarised in Table 2.

Episodes of heavy snow and frost were also reported by officials and settlers. When heavy snow fell in Hobart on

TABLE 2
Reported floods in Tasmania 1803–1840

Year	Date/s	Region	References
1805	Aug–Oct	North	*Historical Records of Australia* 1921a: 639, *Sydney Gazette* 1805
1809	March	South	*Hobart Town Gazette* 1816a: 13 July
1809	Winter	North	*Historical Records of Australia* 1921a:761
1812	November	North	LSD355/1/9 1812
1816	July–Aug	South: North	*Hobart Town Gazette* 1816a: 13 July, 1816b: 20 July, 1816c: 10 August
1818	June	South; North	*Historical Records of Australia* 1921b:332–333
1818	Aug–Sept	South; North	*Historical Records of Australia* 1921b:482–484, Jevons 1859
1819	Feb–March	South	*Hobart Town Gazette* 1819: 20 March
1819	23–25 Sept	South	*Hobart Town Gazette* 1819a: 25 September
1819	Oct–Nov	South; North	*Historical Records of Australia* 1921b: 423, *Hobart Town Gazette* 1819b: 30 October
1822	Sept–Oct	South; North	*Hobart Town Gazette* 1822: 21 September
1825	Oct–Nov	South	Nicholls 1977:461–462
1826	Au—Oct	South; North	McKay 1962: 21–22, Nicholls 1977: 488, *Hobart Town Gazette* 1826: 30 September
1828	July–Sept	South; North	Nicholls 1977:521–523, *Hobart Town Courier* 1828b: 20 September, 1828c: 27 September
1829	June–July	North	*Launceston Advertiser* 1829a: 22 June, 1829b: 6 July
1832	June–July	South; North	*Hobart Town Courier* 1832d: 8 June, 1832e:13 July, *Launceston Advertiser* 1832d: 3 July, 1832e:10 July
1834	Sept	South	Nicholls 1977:636, *Hobart Town Courier* 1834c: 12 September
1836	25–27 February	South; North	*Hobart Town Courier* 1836a: 4 March, 1836b: 28 April, *Mercury* 1882: 13 April
1838	June	South	*Hobart Town Courier* 1838: 29 June

Floods in this table refer to reported episodes when waterways overflowed causing inconvenience and/or damage for human activity and infrastructure, such as roads, bridges, farms and town buildings.

30 June 1814 Knopwood penned in his diary that snow lay "ankle deep on the ground" (Nicholls 1977, p. 182). Further heavy falls were recorded in Hobart in the winters of 1820 and 1830 (Nicholls 1977, *Hobart Town Gazette* 1820, Chapman 1985, *Hobart Town Courier* 1830). Farmer William Pike of Jericho recorded at the bottom of his weather table that on 13 July 1830 the snow was "the deepest" he had ever seen in the colony (RS38/4 1830).

Severe frosts and ice were widespread in the winter of 1837 (Nicholls 1977, *Cornwall Chronicle* 1837a):

> *On Thursday and Friday nights the weather was most severely cold, the oldest inhabitants never having experienced anything like it before. The River Derwent above Hobart Town, in most of the bays was frozen over, and the creeks were clogged with ice.* (Colonial Times 1837, p. 7)

Other early government despatches and diary entries provide evidence of storms and violent gales. On 1 October 1804 a violent gale was experienced in Hobart. Knopwood recorded in his diary:

> *At 1 am it blew a perfect hurricane; many trees and a store tent upon Hunters Island was blown down. At 4 I expected every moment that my marquee would have been blown down. At 10 the wr. began to moderate.* (Nicholls 1977, p. 62)

Other notable gales occurred in Hobart on 4 April 1823 and 17 December 1836 and in Launceston on 19 May 1832 (Nicholls 1977, *Launceston Advertiser* 1832f).

CONCLUSION

These brief summaries demonstrate the range of historical evidence relating to Tasmania's weather prior to the commencement of official meteorological recording in 1840. A range of sources, including early meteorological journals, official despatches, surveyors' notes, diaries, and descriptive newspaper accounts can all assist in revealing a broad picture of Tasmania's recent climatic past and the impacts of climate on early European settlement. It is possible to identify predominantly wet or dry periods, as well as when floods, storms, bushfires and periods of severe cold, heavy snow or frost occurred. The historical sources also provide important information on regional climatic differences in the past. While such historical documentary sources may be primarily descriptive and thereby dismissed as "unscientific", their significance in advancing our knowledge of past climatic regimes should not be overlooked.

REFERENCES

Brown, P. (ed.) 1935: *The Narrative of George Russell of Golf Hill: with Russellania and Selected Papers.* Oxford University Press, London: 469 pp.

Brown, P. (ed.) 1941–1959: *The Clyde Company Papers. Volume 2.* Oxford University Press, London: 482 pp.

Bureau of Meteorology, 2008: *Tasmania's Weather Tales: One Hundred Years of Weather and Climate Services in Tasmania and Antarctica.* Australian Government, Melbourne: 16 pp.

Chapman, P. (ed.) 1985: *The Diaries and Letters of GTWB Boyes. Volume 1: 1830-1832.* Oxford University Press, Melbourne: 692 pp.

CO 201 1804–1805: reel 25: 51, Col. Paterson's Meteorological Journal, Port Dalrymple. Colonial Office Correspondence, Australian Joint Copying Project. Tasmanian Archives and Heritage Office.

CSO1/1/230/5605 1831: Colonial Surgeon's Correspondence to the Colonial Secretary. Archives and Heritage Office of Tasmania, Hobart.

Colonial Times 1837: 4 July: 7.

Cornwall Chronicle 1835: 18 July: 2, 1837a: 1 July: 2, 1837b: 8 July: 2, 1839: 5 January: 2, 1841: 20 January: 2.

Fawkner, J.[c1856], 2007: *Reminiscences of Early Hobart Town 1804-1810.* J. Currey (ed.), Banks Society, Malvern: 108 pp.

Gergis, J. & Fowler, A. 2009: A history of ENSO events since AD 1525: Implications for future climate change. *Climatic Change*, **92**: 343–387.

Gergis, J., Garden, D. & Fenby, C. 2010: The influence of climate on the first European settlement of Australia: A comparison of weather journals, documentary data and palaeoclimate records, 1788–1793. *Environmental History* **15:** 485–507.

Heathcote, R. 1973, Drought perception. *In* Lovett, J. (ed.): *The Environmental, Economic and Social Significance of Drought.* Angus and Robertson, Sydney: 17–40.

Historical Records of Australia, 1921a, Series III, Volume 1. Library Committee of the Commonwealth Parliament, Sydney: 920 pp.

Historical Records of Australia, 1921b, Series III, Volume 2. Library Committee of the Commonwealth Parliament, Sydney: 870 pp.

Historical Records of Australia, 1921c, Series III, Volume 3. Library Committee of the Commonwealth Parliament, Sydney: 1052pp.

Historical Records of Australia, 1921d, Series III, Volume 4. Library Committee of the Commonwealth Parliament, Sydney: 974pp.

Historical Records of Australia, 1921e, Series III, Volume 5. Library Committee of the Commonwealth Parliament, Sydney: 959pp.

Hobart Town Advertiser 1839: 28 June: 2.

Hobart Town Courier 1827a: 15 December: 1, 1827b: 22 December: 2, 1828a: 12 January: 1, 1828b: 20 September: 2 , 1828c: 27 September: 3, 1828d: 4 October: 2, 1830: 17 July: 3, 1831a: 12 January: 2, 1831b: 5 November: 2 , 1831c: 17 December: 2, 1832a: 4 February: 3, 1832b: 11 February: 2, 1832c: 7 April: 2, 1832d: 8 June: 2, 1832e: 13 July: 3, 1834a: 6 June: 2, 1834b: 25 July: 2, 1834c: 12 September: 2, 1835a: 13 February: 2, 1835b: 25 September: 4, 1836a: 4 March: 2, 1836b: 28 April: 3, 1838 : 29 June: 2, 1840: 29 May: 3, 1841: 22 January: 2.

Hobart Town Gazette 1816a: 13 July: 2, 1816b: 20 July: 2, 1816c: 10 August: 2, 1819: 20 March: 2, 1819a: 25 September: 2, 1819b: 30 October: 1, 1820: 2 September: 2, 1821a: 6 January: 2, 1821b: 20 October: 2, 1822: 21 September: 2, 1826: 30 September: 2, 1827: 24 March: 4.

Humphrey, A. 1984: *Narrative of a Voyage to Port Phillip and Van Diemen's Land with Lt. Gov. Collins, 1803-1804.* J. Currey (ed.), Colony Press, Melbourne: 221 pp.

Jevons, W. 1859: Some data concerning the climate of Australia and New Zealand, *Waugh's Australian Almanac: for the Year 1859.* James William Waugh, Sydney: 47–98.

Launceston Advertiser 1829a: 22 June: 5, 1829b: 6 July: 3, 1830: 1 March: 2,1832a: 29 February: 5, 1832b: 19 June: 3, 1832c: 26 June: 5, 1832d: 3 July: 6, 1832e: 10 July: 5, 1832f: 23 May: 3.

Lempriere, T. 1842: A meteorological table, taken from the observations made at Port Arthur, from 1st July, 1837, to the 30th June, 1841. *Tasmanian Journal of Natural Science* **1**: 225.

Lempriere, T. 1846: Meteorological observations made at Port Arthur, during the year 1842. *Tasmanian Journal of Natural Science* **2**: 70.

Lempriere, T. 1954 [1839]: *The Penal Settlements of Early Van Diemen's Land.* Royal Society of Tasmania, northern branch, Launceston: 111 pp.

LSD355/1-3 1803–1804: Land and Survey Department – Field

Notes of James Meehan. Tasmanian Archives and Heritage Office.

McKay, A. 1962: *Journals of the Land Commissioners of Van Diemen's Land 1826-1828*. Tasmanian Historical Research Association, Hobart: 151 pp.

Milligan, J. 1842a: Statement of the fall of rain at the Van Diemen's Land Company's establishment, Hampshire Hills, during the years 1835–1839. *Tasmanian Journal of Natural Science* **1**: 78.

Milligan, J. 1842b: Abstract of meteorological observations at the Van Diemen's Land Company's establishment, Hampshire Hills, V.D.L (1835). *Tasmanian Journal of Natural Science* **1**: 380.

Milligan, J. 1846: Abstract of meteorological observations at the Van Diemen's Land Company's establishment, Hampshire Hills, V.D.L (1836). *Tasmanian Journal of Natural Science* **2**: 71.

Nicholls, M. (ed.) 1977: *The Diary of the Reverend Robert Knopwood; First Chaplain of Van Diemen's Land 1803-1838*. Tasmanian Historical Research Association, Hobart: 738 pp.

NS37/1/1 1841: Records of the Rossbank Observatory, Hobart. Tasmanian Archives and Heritage Office.

Pyne, S. 1991: *Burning Bush: A Fire History of Australia*. Henry Holt and Company, New York: 520 pp.

RS38/4 1826–1840: William Pike 'Park Farm' Jericho records. University of Tasmania, Royal Society Archives, Sandy Bay, Tasmania.

Sydney Gazette 1805: 8 September, p. 2.

Tasmanian and Austral-Asiatic Review 1835: 21 August: 271.

True Colonist 1839: 30 August: 6.

Van Diemen's Land Company (VDL Co.), 1989: *Reports Made to the Yearly General Meeting of the Van Diemen's Land Company 1827-1862* (nos 2-87). National Library of Australia, Canberra.

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ESTABLISHING A MONITORING PROGRAM FOR TASMANIA'S MONTANE CONIFERS

by Nicholas B. Fitzgerald and Jennie Whinam

(with five text-figures, four plates, one appendix and one table)

FITZGERALD, N.B. & WHINAM, J. 2012 (14:xii) Establishing a monitoring program for Tasmania's montane conifers. *Papers and Proceedings of the Royal Society of Tasmania* 146: 9–24. ISSN 0080-4703. Biodiversity Conservation Branch, Department of Primary Industries, Parks, Water & Environment, GPO Box 44, Hobart, Tasmania 7001, Australia (NBF, JW*). *Author for correspondence. Email: Jennie.Whinam@dpipwe.tas.gov.au

Tasmania's relictual cool temperate conifer flora is at risk from projected climate change during this century. Montane and rainforest conifer species exhibit several characteristics which indicate likely vulnerability to environmental change. They are adapted to cool and wet conditions and are highly sensitive to drought and fire. Increased moisture stress and fire are therefore expected to drive declines and local extinctions in these species with ecosystem-changing consequences. A long-term monitoring program has been established to examine trends in condition and recruitment for four Tasmanian endemic conifer species. Permanent monitoring sites have been established at 13 locations in Tasmania's highlands. The target species include two long-lived, slow-growing rainforest tree species – Pencil Pine (*Athrotaxis cupressoides*) and King Billy Pine (*A. selaginoides*) – and two shrubby conifers typically associated with high elevation coniferous heath vegetation – Dwarf Pine (*Diselma archeri*) and Drooping Pine (*Pherosphaera hookeriana*). Conifer condition was assessed visually using four condition classes. Presence of juvenile plants was recorded as were cones (strobili) on mature plants. Conifers were mostly in good condition, with Drooping Pine the only species to frequently exhibit poorer condition. Condition varied significantly between sites for Pencil Pine but not for King Billy Pine. No recruitment of Pencil Pine was evident at the majority of its sites (23 of 34), whereas seedlings and juveniles were present at most King Billy Pine sites (20 of 24). Recruitment appeared to be more or less continuous for the shrubby conifer species.
Key Words: conifers, monitoring, climate change, Tasmania, *Athrotaxis cupressoides, Athrotaxis selaginoides, Diselma archeri, Microcachrys tetragona, Pherosphaera hookeriana, Pherosphaera lawrenci.*

INTRODUCTION

Tasmania has 10 native species of conifers (Division Pinophyta) of which eight are relictual species of rainforest and montane habitats (Hill 1998, Hill & Orchard 1999). Within Australia, Tasmania's cool temperate conifer flora has high levels of diversity and endemism (Enright & Hill 1995) and Tasmania is one of five global hotspots of conifer diversity (Contreras-Medina *et al.* 2001). The 50% endemism rate at the generic level is among the highest rates of endemism in conifer floras worldwide (Contreras-Medina & Vega 2002). Rainforest and alpine vegetation communities dominated by conifers are internationally significant due to their primitive flora and Gondwanan affinities (Balmer *et al.* 2004) and presently cover less than 1% of Tasmania's land area.

A dramatic decline in the extent, diversity and dominance of Australian conifers during the Tertiary coincides with increasing aridity in this period, with many of the relictual species now restricted to Western Tasmania, which is a refugium for conifers (Jordan 1995, Carpenter *et al.* 2011).

Most Tasmanian conifers exhibit physiological drought intolerance (Brodribb & Hill 1998) and are extremely fire sensitive (Gibson *et al.* 1995, Kirkpatrick *et al.* 2010). Vulnerability to climate change is determined by a complex range of factors broadly comprising adaptive capacity, resilience and exposure (Williams *et al.* 2008). Montane conifer species possess many of the characteristics associated with vulnerability to climate change (Williams *et al.* 2008): (i) poor physiological tolerances to high temperature and low moisture availability; (ii) life history traits including longevity, slow growth rates and poor dispersal; (iii) present limited geographic range; and (iv) predicted exposure to climate change (based on downscaled general circulation models for Tasmania; Grose *et al.* 2010). Therefore, local extinctions and consequent range contractions are likely to occur in these species. Uncertainties such as ecological and evolutionary adaptive responses and potential feedbacks and interactions make it difficult to predict how fast and widespread these impacts will be.

There have been many episodes of rapid climate change – most recently during the Quaternary glacial cycles – with relatively few extinctions, suggesting that species have been able to persist, evolve or migrate more successfully than is predicted by current models (Botkin *et al.* 2007). However, the additive effects of pressures such as increased fire, herbivory, low levels of recruitment and physiological stress may increase the likelihood of extinctions.

Dieback symptoms such as chlorosis, foliage thinning and death have been observed in several conifer species at widespread locations in Tasmania's highlands. These symptoms may be pathological (e.g., Whinam *et al.* 2001, Yuan *et al.* 2000) or environmental. Changes in vegetation condition can be related to a variety of causes and manifest at different scales ranging from individuals, to populations, to the overall extent of the community. Observation and monitoring at different scales is therefore a strategic approach to detect and quantify change, which can inform adaptive management strategies such as protection of refugia, *ex situ* conservation and assisted migration.

Four Tasmanian endemic conifer species have been selected for long-term monitoring. These species are expected to be sensitive to environmental change and consequently are

likely to be useful indicator species. They exhibit different life histories, are keystone species in several vegetation communities of conservation significance and are also iconic elements of the Tasmanian environment. Most populations of these conifers occur in reserves, particularly the Tasmanian Wilderness World Heritage Area where they contribute to the globally significant flora and vegetation values (fig. 1).

King Billy Pine (*Athrotaxis selaginoides* D. Don) and Pencil Pine (*A. cupressoides* D. Don) are slow-growing rainforest trees with a lifespan of around 1300 years (Cullen & Kirkpatrick 1988a, b, Gibson *et al.* 1995). King Billy Pine is a canopy dominant or emergent tree in mid-elevation climax rainforests (typically 360–1100 m), and also occurs in krumholz (dwarf) form in alpine scrub. Pencil Pine is a highland species, mostly occupying an altitudinal range of 990–1370 m, where it is dominant in subalpine rainforest and woodland and also occurs in alpine vegetation (Kirkpatrick 1996). Both species exhibit mast seed production with seed dispersal by wind typically limited to around 100 m, although Pencil Pine relies mostly on asexual reproduction with root suckers observed more than 50 m from a parent plant (Cullen & Kirkpatrick 1988a, b, Kirkpatrick *et al.* 2010).

Dwarf Pine (*Diselma archeri* Hook.f.) is a dense shrub typically 0.5–1.5 m tall in alpine heathland, but occasionally taller in subalpine forest. There is a small atypical population of this species at Lake Johnston in the West Coast Range where it occurs as a tree reaching heights of over 10 m with diameter at breast height (DBH) up to 45.5 cm (Fitzgerald 2011). Drooping Pine (*Pherosphaera hookeriana* W. Archer syn. *Microstrobos niphophilus* J.Garden & L.A.S.Johnson) is similar in appearance, habitat and dioecious habit; however, the two species are in different families. Drooping Pine has a more limited distribution (fig. 1) and our observations suggest that it always co-occurs with Dwarf Pine. Both species are dominants of coniferous heathland, which may also include Creeping Pine (*Microcachrys tetragona* Hook.), Mountain Plum Pine (*Podocarpus lawrencei* Hook.f.) and shrubby forms of the two *Athrotaxis* species. Coniferous heathland occurs at high elevations, typically 1070–1490 m.

Observed climate change in Tasmania includes a rise in mean annual temperature of 0.1°C per decade since the 1950s and changed rainfall seasonality (Grose *et al.* 2010) with regional variation in magnitude and direction of change. Ecological impacts in the Tasmanian highlands are already apparent; notably severe dieback of Cider Gum (*Eucalyptus gunnii* ssp. *divaricata* McAulay & Brett) on the eastern Central Plateau which appears to be largely driven by drought associated with a long-term decline in rainfall (Calder & Kirkpatrick 2008).

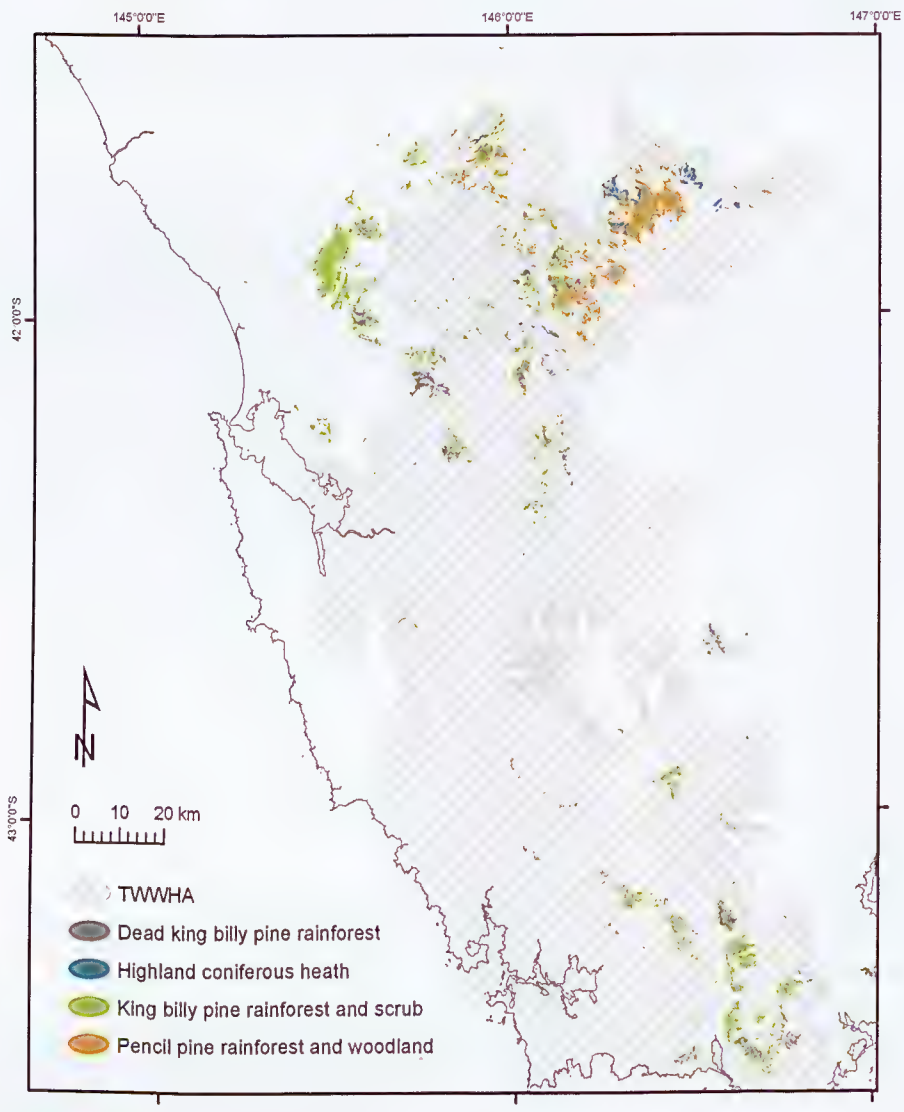

FIG. 1 — Distribution of vegetation communities dominated by the four conifer species targeted for monitoring. Shaded area is the Tasmanian Wilderness World Heritage Area. Vegetation mapping from TASVEG 2.0.

Recent climatic projections for Tasmania indicate little change for central and western Tasmania until after 2040, when there is likely to be a reduction in annual rainfall for the Central Plateau (core range of Pencil Pine) and a marked decrease in summer rainfall in the central west which coincides with the core range of King Billy Pine (Grose *et al.* 2010). Based on six global climate model simulations downscaled for Tasmania, the Central Highlands and western Tasmania are expected to experience increases (from the baseline period 1978–2007) in average and maximum temperatures of approximately 1–2°C during 2040–2069, increasing to 2.5–3°C after 2070; this magnitude of change is expected to be year-round on the Central Plateau, while the West Coast is likely to see more warming in summer than other seasons (Grose *et al.* 2010).

Ecophysiological studies show that King Billy Pine is adapted to cool temperatures (Read & Busby 1990) and is poorly adapted to water stress (Brodribb & Hill 1998, Jordan *et al.* 2004). Read & Busby (1990) suggest that low summer rainfall is the primary limitation for King Billy Pine based on bioclimatic modelling, while their physiological research indicates high summer temperatures are directly limiting, at least at lower elevations where rainfall is adequate. The difficulty of interpreting the climatic niche is compounded by the substantial influence of fire and slow dispersal ability on the realised niche and the possibility that present distributions of vegetation with conifers may reflect past climatic events (Read & Busby 1990).

Pencil Pine, King Billy Pine and Drooping Pine are capable of asexual reproduction by layering or suckering (Cullen & Kirkpatrick 1988a, Gibson *et al.* 1995, TSS 2009). The relative importance of seedling versus vegetative reproduction appears to vary between species and sites.

Cunningham *et al.* (2007) suggest using the term "condition" to describe the appearance of a tree, while "health" refers to actual physiological and pathological factors. This paper describes the method employed for monitoring the condition and recruitment of Tasmania's montane conifer species and provides a baseline for assessing change in the future. The monitoring method presented here is a relatively simple and efficient system for documenting long-term trends in recruitment and condition of flora species and can be applied to other species in Tasmania and elsewhere.

METHODS

Thirteen localities were selected for conifer monitoring, covering much of the geographic extent of the four target conifer species (fig. 2). All sites are recorded on the Parks & Wildlife Service Information Management System (PWSIMS).

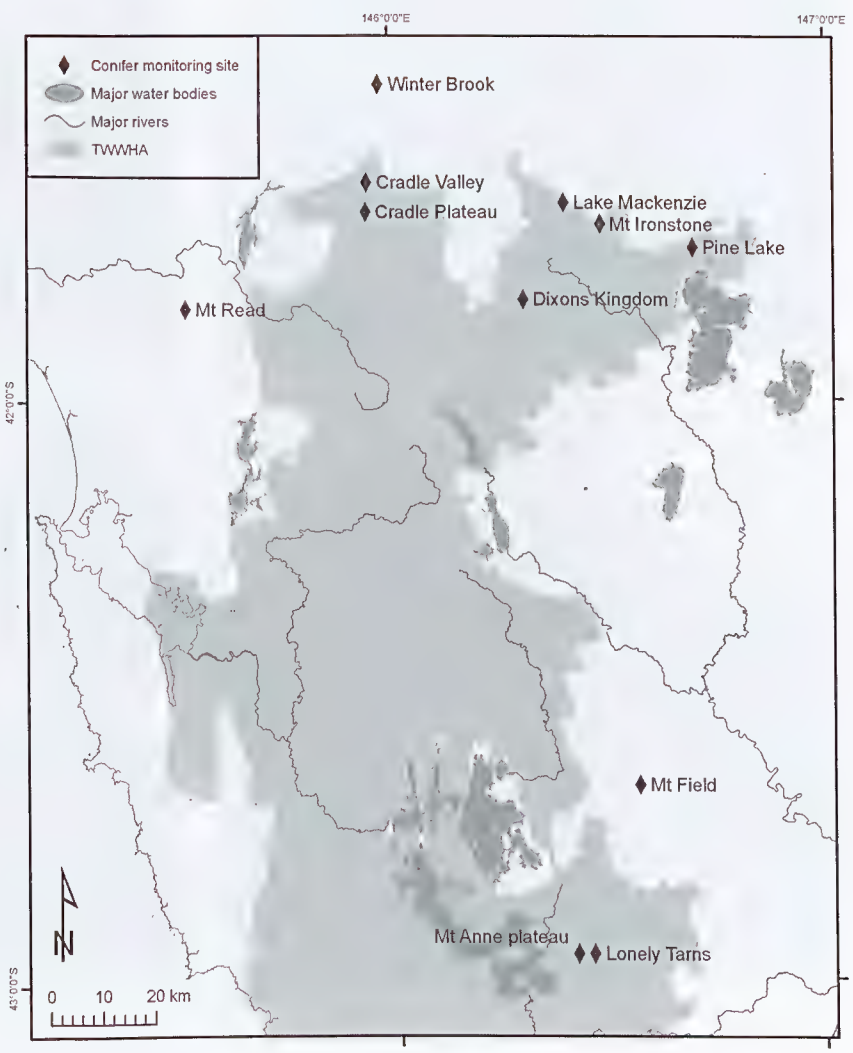

FIG. 2 — Location of montane conifer monitoring sites in Tasmania.

Site description

For each plot the slope, aspect, geology, landform, fire history, vegetation community and ground cover were recorded (see appendix 1). Floristic description involved recording dominant vascular plant species and cover scores by stratum and lifeform categories.

Athrotaxis forest monitoring

Monitoring for *Athrotaxis* forest and woodland uses a modified point-centred quarter method (PCQM) where each "plot" consists of 12 *Athrotaxis* "individuals" and sampling is based on a permanently marked centre-point. The nearest three *Athrotaxis* trees over 2 m tall are recorded within each of four quadrants delineated by the cardinal compass points. PCQM is widely used for forest inventory surveys as it is more efficient than plot-based sampling and although it is designed for single-trunked upright trees it can be adapted to situations where trees have multiple or leaning trunks (Dahdouh-Guebas & Koedam 2006, Mitchell 2007). Using this method there is theoretically no distance limit for inclusion of trees from the centre-point; however, in practice with small discrete stands of *Athrotaxis* there may be a quarter in which there are fewer than three trees. In this case a correction factor can be applied to the PCQM data to adjust for vacant quarters, or for fewer than 12 individuals (Mitchell 2007). The formula used to estimate density assumes a random distribution of trees which is rarely the case in nature (Mitchell 2007). Pencil Pine appears to have a distinctly clumped distribution in most cases, particularly in woodland communities. Consequently the results must be considered estimates of stand density rather than definitive measures.

Multi-trunked trees where the trunks clearly arise from a common base are recorded as an individual, as are distinct clusters of stems. Root suckers or trunks distant from the cluster (more than c. 1.5 m) are treated separately, even if it appears that they may be connected. Suckering in Pencil Pines results in clonal stands (Cullen & Kirkpatrick 1998b), so it is not feasible or desirable for a field monitoring program to define individuals on a genetic basis.

For each of the 12 "individuals" at a site the following details were recorded: distance and direction from marker post; DBH at 1.3 m (for rare instances where many small stems occur in addition to one or more of larger diameter measure all stems that are more than ¼ the diameter of the largest stem); chlorosis or death of apical foliage (recent/old/absent); cones (absent, present on <50% of branches, present on >50% of branches); age (current season or older) and predominant sex of cones; and an overall condition score ranging from 1 (dead) to 4 (no dieback symptoms). Reference photographs of conifers representing the different condition scores are used as a guideline for assigning the four condition classes (see pls 1–4). The simple four-class condition score was chosen to provide repeatability and reduce observer bias compared to a larger number of classes.

While other researchers have used several indices of tree condition (e.g., crown extent, crown density, crown vigour, leaf condition) for trees with well-defined architecture and dieback processes (e.g., Cunningham *et al.* 2007, Souter *et al.* 2010a, b), this has proved impractical for *Athrotaxis* species due to considerable variability in tree form, which is likely to be related to age and site characteristics.

Recruitment was noted for all conifer species present with the following categories: none, seedling, asexual, seedling and asexual, indeterminate. In addition to the 12 trees per plot any smaller *Athrotaxis* individuals (under 2 m tall) are recorded with location relative to the centre point and a height estimate.

Classification and ordination of plots were performed on the mean health score of trees using PATN (Belbin 1993). Classification used the Agglomerative Hierarchical Fusion, with Gower Metric Association Measure and Flexible UPGMA and SSH ordination method.

Highland coniferous heathland monitoring

For coniferous shrubbery (and *Athrotaxis* vegetation under 2 m tall) sampling is based on 10 x 10 m quadrats oriented to magnetic north and marked with permanent aluminium corner stakes. For each conifer species in a quadrat the following details were recorded: percentage cover (Braun-Blanquet scale); average and maximum height; cones (absent, present on <50% of branches, present on >50% of branches); age and predominant sex of cones; and an overall condition score ranging from 1 (dead) to 4 (no dieback symptoms). Recruitment was noted for all conifer species present with the following categories: none, seedling, asexual, seedling & asexual, indeterminate.

Apart from the four target species, the same observations were also recorded for other conifer species when present at a site.

RESULTS

Recruitment was evident at 11 out of 34 sites for Pencil Pine, with most, or possibly all, juveniles being root suckers. Recruitment was most frequent at Mount Field, followed by Pine Lake, with very little or no recruitment observed at the other study sites. Recruitment was more frequent for *A. selaginoides* with juveniles present at 20 out of 24 sites. All King Billy Pine recruitment appeared to be from seed except at Mount Read where there were apparent root suckers, although further investigation would be required to determine their origin. Some sites had large numbers of small seedlings (less than c. 3 cm tall) but larger seedlings were infrequent.

Condition scores for Pencil Pine show a significant difference between sites (Kruskal-Wallis test, $p < 0.001$) with Mount Field and Mount Ironstone having a median condition score of 3 while the other sites have a median of 4 (table 1). There is no significant difference between sites for *A. selaginoides* with all sites having a median score of 4 (Kruskal-Wallis test, P-Value = 0.067).

Pine Lake (fig. 3) is the only location where condition scores appear to be related to tree size, as measured by DBH (Kruskall-Wallis test, $p = 0.012$), while Lake Mackenzie and Mount Ironstone display a significant relationship at the 10% confidence level. These sites are all located on the northern part of the Central Plateau and are dominated by Pencil Pine, although the nearby Mickeys Creek site does not show a similar relationship.

Recruitment of the shrubby conifer species was evident at most sites, although it was not feasible to distinguish seedlings from root suckers. Instances where no recruitment was observed were usually associated with very low coverage of that particular species in the plot (e.g., only one mature plant present). Continuous vegetative reproduction appears to be commonplace in Drooping Pine and Dwarf Pine. Variation in timing of surveys precludes useful comparison of cone production between sites since the strobili (cones)

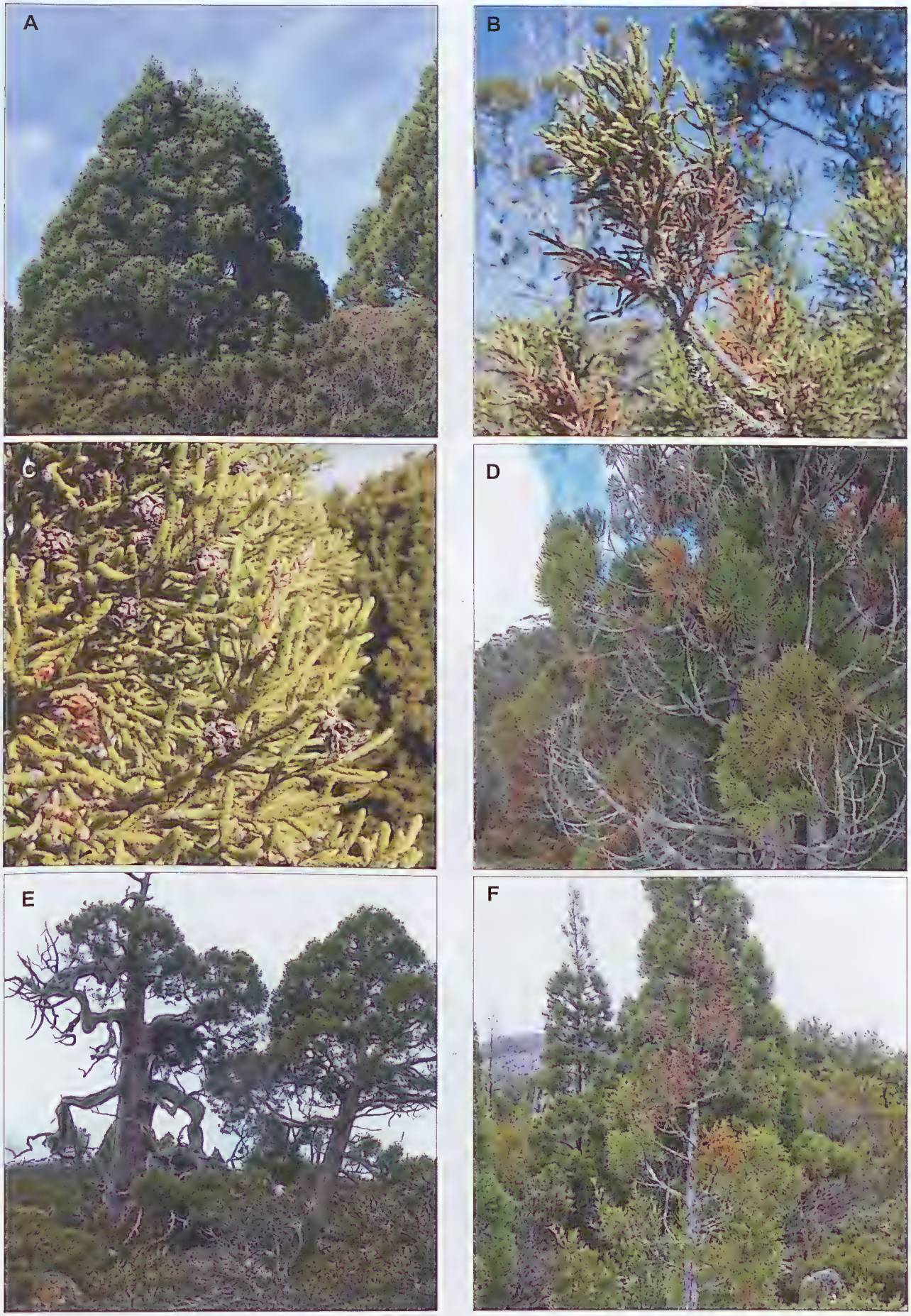

PLATE 1

Examples of Pencil Pine, Arthrotaxis cupressoides, *condition classes: (A), (B) = 4; (C), (D) = 3; (E), (F) = 2.*

PLATE 2

Examples of King Billy Pine, Athrotaxis selaginoides, *condition classes: (A), (B) = 4; (C), (D) = 3; (E), (F) = 2.*

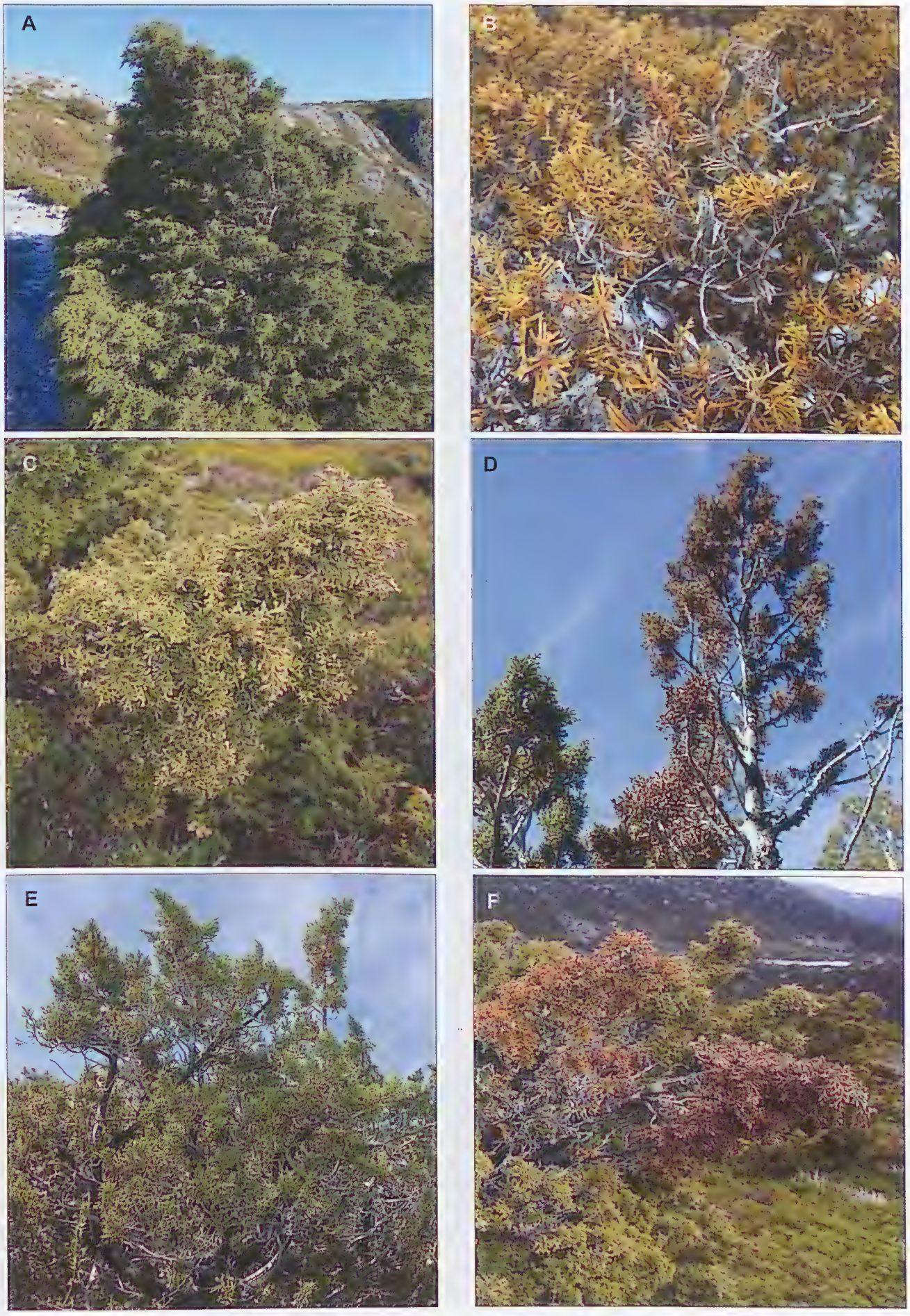

PLATE 3
Examples of Dwarf Pine, Diselma archeri, *condition classes: (A), (B) = 4; (C), (D) = 3; (E), (F) = 2.*

PLATE 4
Examples of Drooping Pine, Pherosphaera hookeriana, *condition classes: (A), (B) = 4; (C), (D) = 3; (E), (F) = 2.*

TABLE 1
Frequency of tree condition scores by species and site.

Species	Location	Condition[1] Score				Total
		1	2	3	4	
Arthrotaxis cupressoides	Cradle Valley			1	21	22
	Dixons Kingdom		3	24	93	120
	Lake Mackenzie			16	32	48
	Mickeys Creek		3	14	19	36
	Mount Field		3	35	22	60
	Mount Ironstone			23	13	36
	Pine Lake		4	31	37	72
	Total		13	144	237	382
A. selaginoides	Cradle Valley		1	9	26	36
	Mount Read			27	53	80
	North East Ridge	1	1	7	50	59
	Winter Brook		1	9	46	56
	Total	1	3	52	175	231
A. Xlaxifolia	Cradle Valley				2	2
	Mount Read			2		2
	Total			2	2	4
Diselma archeri	Mount Read				14	14
	Total				14	14
Total		1	16	198	428	643

[1] Condition class ranges from 1 (dead) to 4 (good condition).

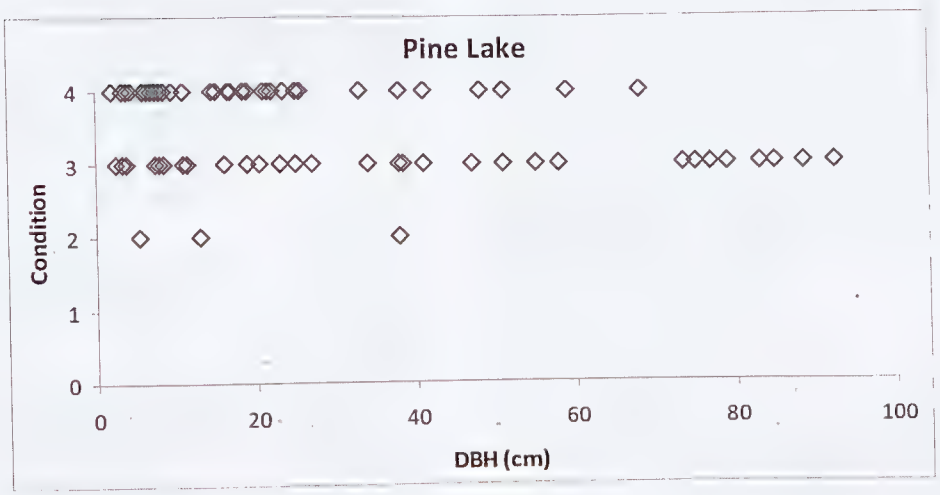

FIG. 3 — Condition scores for Pencil Pine individuals at Pine Lake related to trunk diameter.

are not retained on the plant for more than a few weeks, unlike in *Athrotaxis*.

Dwarf Pine generally exhibited good condition, with 26 out of 30 quadrats having an average condition of 4 (fig. 4). Drooping Pine quadrats were evenly split between those averaging 3 and 4. Ordination analysis (Belbin 1993) indicates that aspect and slope are the most significant variables discriminating the two groups, with good condition (Group 2, score = 4) associated with steeper slopes and more southwesterly aspects (fig. 5).

DISCUSSION

Size class distributions of conifer trees at the study sites indicate continuous or episodic regeneration for Pencil Pine with more episodic recruitment for King Billy Pine (Fitzgerald 2011), which supports recruitment patterns previously reported for these species (Cullen & Kirkpatrick 1988b, Cullen 1991).

Long-term recruitment failure (dating back at least until the first half of the nineteenth century) of Pencil Pine on the Central Plateau in open grassy montane rainforest has in the past been attributed to high levels of grazing pressure from wallabies (*Macropus rufogriseus* (Desmarest, 1817)) and rabbits (*Oryctolagus cuniculus* Linnaeus, 1758), possibly due to the removal of top order predators (Cullen & Kirkpatrick 1988a). However, recruitment observed during our study at Pine Lake but not at similar habitat at Mickeys Creek suggests that other factors may also play a role.

Natural processes such as intraspecific competition and aging can influence tree condition so caution is required when interpreting tree condition and dieback. For example, at Pine Lake none of the largest individuals were classified in the highest condition class, probably due to natural senescence. Similarly the poorest condition individuals occur in the smaller size classes and apparently reflect natural thinning.

Seasonal and interannual variations in condition and phenology are natural phenomena and therefore robust long-term datasets are needed to identify real trends. A further complication is the difficulty of meaningful assessment of tree condition in exposed environments, where trees are deformed and defoliated by weather conditions, but may be healthy despite having features such as dead branches (or trunks), reduced crown size or bark stripped by ice storms.

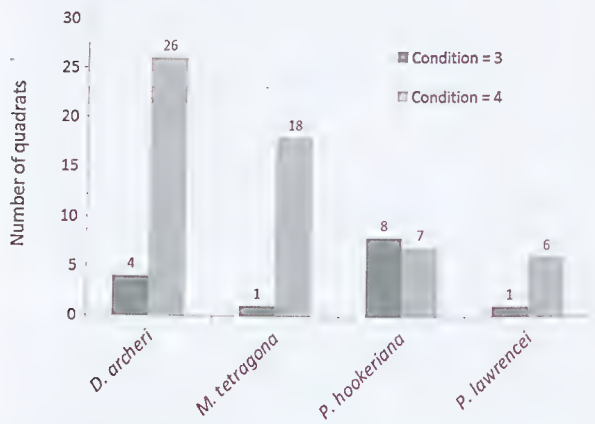

FIG. 4 — Number of quadrats by average condition class for shrubby conifer species, Diselma archeri, Microcachrys tetragona. Pherosphaera hookeriana, *and* P. lawrenci. *Condition class ranges from 1 (dead) to 4 (good condition.*

Extreme events such as drought and heatwaves (White *et al.* 2010) and consequent increases in fire severity and frequency (Williams *et al.* 2009) are likely to have more impact on conifers than shifts in mean temperature and rainfall. Rainforest and alpine vegetation is at risk of increased frequency and intensity of fire events if recent trends of increased incidence of dry lightning and drier soil conditions in western Tasmania continue (DPIPWE 2010). Predicting the locations of likely future climatic and fire refugia for montane conifers would help inform the conservation management of these species, especially in terms of fire protection priorities.

In all four conifer species, both plants and seeds are readily killed by fire. The four conifers have poor seed dispersal which limits the possibility of successful recolonisation (Kirkpatrick & Dickinson 1984). Although King Billy Pine can recolonise or regenerate after fire in some circumstances, it is more commonly eliminated by fire (Cullen 1987). Palynological profiles provide strong evidence for local extinctions of conifer species due to fire and in some cases reoccupation has not occurred after thousands of years (Cullen & Kirkpatrick 1988a, Kirkpatrick & Dickinson 1984).

Warmer temperatures are expected to increase the altitude of the treeline (Richardson & Friedland 2009), theoretically resulting in subalpine forest migrating upslope. Given the longevity and slow growth of *Athrotaxis*, migration of *Athrotaxis* forest would be slow but the already established shrubby *Athrotaxis* at higher altitudes would provide a basis for forest development at sites previously marginal for tree species, dependent on factors such as wind and snow in addition to temperature (Green 2009). Observed mortality of Snow Peppermint (*Eucalyptus coccifera* Hook.f.) co-occurring with Pencil Pine is likely due to severe frosts (Cullen & Kirkpatrick 1988b), so a reduction in the severity of frost might be expected to facilitate eucalypt invasion of Pencil Pine woodland.

Changes in phenology are expected in response to environmental change, either through physiological responses to environmental cues or as a response to stress. Phenological

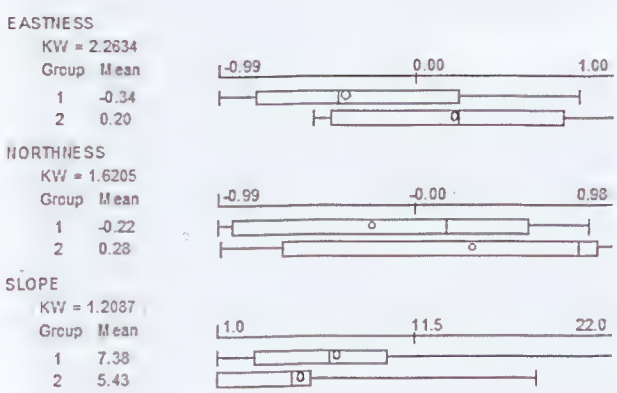

FIG. 5 — Box-plots of the three most significant variables (KW = Kruskall-Wallis statistic) discriminating between two groups of plots based on condition scores for Drooping Pine. Group 1 is plots with an average condition class of 3 (representing somewhat poor condition) while Group 4 plots have an average condition class of 4 (good condition). Box represents quartiles, whiskers are the range, vertical line is median, diamond is mean. An eastness value of 1 = due east while -1 = due west, similarly northness value of 1 = due north and -1 = due south.

changes can be variable and difficult to predict within a species, so long-term and geographically broad datasets are needed to determine trends (Primack *et al.* 2009). The phenology of *Athrotaxis* warrants further study and it would be informative to undertake annual monitoring of cone production along with germination trials.

Drooping Pine produces limited quantities of viable seed with a deep physiological dormancy which may result in a semi-persistent soil seed bank (Wood 2011, James Wood, pers. comm.). This is supported by field observations which suggest that seedlings are very rare and reproduction is largely vegetative in this species (TSS 2009).

This survey determines the current condition status across the range of four conifer species, providing a baseline for monitoring of spatial and temporal trends. Additionally, dendrochronology undertaken on *Athrotaxis* species at various locations provides centuries-scale data on growth rates and responses to environmental change by these species (e.g., Allen *et al.* 2011). Long-term changes in the health of conifers at the stand level are likely to occur over decadal scales. If climate change is a driver of health decline, the conifers may not show significant effects until a climatic threshold is reached.

In the future, time series data will be analysed for long-term spatial and temporal trends in conifer condition. The range of monitoring sites provides replication and allows analysis of spatial patterns in condition, particularly if combined with remote sensing techniques. The geographic variation between sites (e.g., altitude) also provides a surrogate for climate and will be useful in examining the potential influence of climatic factors on conifer health.

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REFERENCES

Allen, K., Ogden, J., Buckley, B., Cook, E. & Baker, P. 2011: The potential to reconstruct broadscale climate indices associated with southeast Australian droughts from *Athrotaxis* species, Tasmania. *Climate Dynamics* **37**: 1799–1821.

Balmer, J., Whinam, J., Kelman, J., Kirkpatrick, J.B. & Lazarus, E. 2004: *A Review of the Floristic Values of the Tasmanian Wilderness World Heritage Area.* Nature Conservation Report 2004/3. Department of Primary Industries Water and Environment.

Belbin, L. 1993: *PATN.* http://www.patn.com.au (accessed 25 July 2011).

Botkin, D., Saxe, H., Araujo, M., Betts, R., Bradshaw, R., Cedhagen, T., Chesson, P., Dawson, T., Etterson, J. & Faith, D. 2007: Forecasting the effects of global warming on biodiversity. *Bioscience* **57**: 227–236.

Brodribb, T. & Hill, R.S. 1998: The photosynthetic drought physiology of a diverse group of southern hemisphere conifer species is correlated with minimum seasonal rainfall. *Functional Ecology* **12**: 465–471.

Calder, J.A. & Kirkpatrick, J.B. 2008: Climate change and other factors influencing the decline of the Tasmanian cider gum (*Eucalyptus gunnii*). *Australian Journal of Botany* **56**: 684–692.

Carpenter, R.J., Jordan, G.J., Mildenhall, D.C. & Lee, D.E. 2011: Leaf fossils of the ancient Tasmanian relict *Microcachrys* (Podocarpaceae) from New Zealand. *American Journal of Botany* **98**: 1164–1172.

Contreras-Medina, R. & Luna Vega, I. 2002: On the distribution of gymnosperm genera, their areas of endemism and cladistic biogeography. *Australian Systematic Botany* **15**: 193–203.

Contreras-Medina, R., Morrone, J.J. & Luna Vega, I. 2001: Biogeographic methods identify gymnosperm biodiversity hotspots. *Naturwissenschaften* **88**: 427–430.

Cullen, P.J. 1987: Regeneration patterns in populations of *Athrotaxis selaginoides* D. Don. from Tasmania. *Journal of Biogeography* **14**: 39–51.

Cullen, P.J. 1991: Regeneration of *Athrotaxis selaginoides* and other rainforest tree species on landslide faces in Tasmania. *In* Banks, M.R., Smith, S.J., Orchard, A.E. & Kantvilas, G. (eds): *Aspects of Tasmanian botany: a tribute to Winifred Curtis.* Royal Society of Tasmania, Hobart: 191–200.

Cullen, P.J. & Kirkpatrick, J.B. 1988a: The ecology of *Athrotaxis* D. Don (Taxodiaceae). I. Stand structure and regeneration of *A. cupressoides*. *Australian Journal of Botany* **36**: 547–560.

Cullen, P.J. & Kirkpatrick, J.B. 1988b: The ecology of *Athrotaxis* D. Don (Taxodiaceae). II. The distributions and ecological differentiation of *A. cupressoides* and *A. selaginoides*. *Australian Journal of Botany* **36**: 561–573.

Cunningham, S.C., Read, J., Baker, P.J. & Mac Nally, R. 2007: Quantitative assessment of stand condition and its relationship to physiological stress in stands of *Eucalyptus camaldulensis* (Myrtaceae). *Australian Journal of Botany* **55**: 692–699.

Dahdouh-Guebas, F. & Koedam, N. 2006: Empirical estimate of the reliability of the use of the Point-Centred Quarter Method (PCQM): Solutions to ambiguous field situations and description of the PCQM+ protocol. *Forest Ecology and Management* **228**: 1–8.

DPIPWE 2010: *Vulnerability of Tasmania's natural environment to climate change: an overview.* Department of Primary Industries, Parks, Water & Environment, Hobart." 79 pp

Enright, N. & Hill, R. (eds) 1995: *Ecology of the southern conifers.* Melbourne University Press, Melbourne: 342 pp.

Fitzgerald, N. 2011: Establishment report for Tasmanian Wilderness World Heritage Area Climate Change Monitoring Program: Montane Conifers. Nature Conservation Report Series 11/06. Resource Management and Conservation Division, DPIPWE, Hobart: 96 pp.

Gibson, N., Barker, P., Cullen, P. & Shapcott, A. 1995: Conifers of Southern Australia. *In* Enright, N. & Hill, R. (eds): *Ecology of the southern conifers.* Melbourne University Press, Melbourne: 223–251.

Green, K. 2009: Causes of stability in the alpine treeline in the Snowy Mountains of Australia – a natural experiment. *Australian Journal of Botany* **57**: 171–179.

Grose, M., Barnes-Keoghan, I., Corney, S., White, C., Holz, G., Bennett, J., Gaynor, S. & Bindoff, N. 2010: Climate Futures for Tasmania: general climate impacts technical report. Antarctic Climate and Ecosystems Cooperative Research Centre, Hobart, Tasmania: 72 pp.

Hill, R.S. 1998: 'Gymnosperms' – the paraphyletic stem of seed plants. *In* McCarthy, P.M. (ed.): *Flora of Australia, Volume 48: Ferns, Gymnosperms and Allied Groups.* Australian Biological Resources Study/CSIRO, Canberra: 505–525.

Hill, R.S. & Orchard, A.E. 1999: Composition and endemism of vascular plants. *In* Reid, J.B., Hill, R.S., Brown, M.J. & Hovenden, M.J. (eds): *Vegetation of Tasmania.* Flora of Australia Supplementary Series Number 8, Australian Biological Resources Study, Canberra: 589–124.

Jordan, G.J. 1995: Extinct conifers and conifer diversity in the Early Pleistocene of western Tasmania. *Review of Palaeobotany and Palynology* **84**: 375–387.

Jordan, G.J., Brodribb, T.J. & Loney, P.E. 2004: Water loss physiology and evolution within the Tasmanian conifer genus *Athrotaxis* (Cupressaceae). *Australian Journal of Botany* **52**: 765–771.

Kirkpatrick, J. 1996: *Alpine Tasmania: An Illustrated Guide to the Flora and Vegetation.* Oxford University Press, Melbourne: 196 pp.

Kirkpatrick, J., Bridle, K. & Dickinson, K. 2010: Decades-scale vegetation change in burned and unburned alpine coniferous heath. *Australian Journal of Botany* **58**: 453–462.

Kirkpatrick, J. & Dickinson, K. 1984: The impact of fire on Tasmanian alpine vegetation and soils. *Australian Journal of Botany* **32**: 613–629.

Mitchell, K. 2007: *Quantitative analysis by the point-centered quarter method.* Department of Mathematics and Computer Science, Hobart and William Smith Colleges, New York. 34 pp. http://arxiv.org/pdf/1010.3303.pdf

Primack, R.B., Ibáñez, I., Higuchi, H., Lee, S., Miller-Rushing, A.J., Wilson, A.M. & Silander, J.A., Jr. 2009: Spatial and interspecific variability in phenological responses to warming temperatures. *Biological Conservation* **142**: 2569–2577.

Read, J. & Busby, J.R. 1990: Comparative response to temperature of the major canopy species of Tasmanian cool temperate rainforest and their ecological significance. II. Net photosynthesis and climate analysis. *Australian Journal of Botany* **38**: 185–205.

Richardson, A.D. & Friedland, A.J. 2009: A review of the theories to explain Arctic and alpine treelines around the world. *Journal of Sustainable Forestry* **28**: 218–242.

Souter, N.J., Cunningham, S., Little, S., Wallace, T., McCarthy, B. & Henderson, M. 2010a: Evaluation of a visual assessment method for tree condition of eucalypt floodplain forests. *Ecological Management & Restoration* **11**: 210–214.

Souter, N.J., Watts, R.A., White, M.G., George, A.K. & McNicol, K.J. 2010b: A conceptual model of tree behaviour improves the visual assessment of tree condition. *Ecological Indicators* **10**: 1064–1067.

TSS 2009: Listing Statement for *Pherosphaera hookeriana* (drooping pine). Threatened Species Section, DPIPWE, Hobart: 6 pp.

Whinam, J., Chilcott, N. & Rudman, T. 2001: Impacts of dieback at Pine Lake, Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* **135**: 41–50.

White, C., Sanabria, L., Grose, M., Bennett, J., Holz, G., McInnes, K., Cechet, R., Gaynor, S. & Bindoff, N. 2010: Climate Futures for Tasmania: extreme events technical report. Antarctic Climate and Ecosystems Cooperative Research Centre, Hobart, Tasmania: 88 pp.

Williams, R.J., Bradstock, R.A., Cary, G.J., Gill, A.M., Liedloff, A.C., Lucas, C., Whelan, R.J., Andersen, A.N., Bowman, D. & Clarke, P.J. 2009: Interactions between climate change, fire regimes and biodiversity in Australia: a preliminary assessment. Report to the Department of Climate Change and Department of the Environment, Water, Heritage and the Arts, Canberra: 208 pp.

Williams, S.E., Shoo, L.P., Isaac, J.L., Hoffmann, A.A. & Langham, G. 2008: Towards an integrated framework for assessing the vulnerability of species to climate change. *PLoS Biology* **6**: e325.

Wood, J.A. 2011: RTBG Germination Database. http://www.rtbg.tas.gov.au/tasgerm (accessed 27 July 2011).

Yuan, Z.Q., Rudman, T. & Mohammed, C. 2000: *Pseudophacidium diselmae* sp. nov. isolated from stem cankers on *Diselma archeri* in Tasmania, Australia. *Australasian Plant Pathology* **29**: 215–221.

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APPENDIX 1
Site details for conifer monitoring plots.

LOCATION	SITE	EASTING	NORTHING	ELEV[N]	PLOT TYPE	SLOPE	ASPECT	TASVEG	GEOLOGY	POSITION	LAND-FORM	FIRE HISTORY
Cradle Plateau	CMCH01	412115	5385705	1233	10 x 10 m	7	300	HCH	Quartzite/Schist	Mid Slope	Other	None
Cradle Plateau	CMCH02	412127	5385733	1232	10 x 10 m	5	270	HCH	Quartzite/Schist	Lower Slope	Other	None
Cradle Plateau	CMCH03	412387	5385767	1239	10 x 10 m	7	34	HCH	Quartzite/Schist	Mid Slope	Other	None
Cradle Plateau	CMCH04	412159	5386260	1278	10 x 10 m	4	100	HCH	Quartzite/Schist	Upper Slope	Other	None
Cradle Plateau	CMCH05	412053	5386363	1280	10 x 10 m	2	10	HCH	Quartzite/Schist	Ridge	Other	None
Cradle Plateau	CMCH06	412166	5386590	1249	10 x 10 m	10	30	HCH	Glacial till	Mid Slope	Other	None
Cradle Valley	CVKB01	413157	5390467	990	PCQ	15	160	RKP	Quartzite/Schist	Mid Slope	Other	None
Cradle Valley	CVKB02	413164	5390562	1014	PCQ	15	150	RPW	Quartzite/Schist	Mid Slope	Other	None
Cradle Valley	CVKB03	411935	5389954	945	PCQ	10	165	RKP	Quartzite/Schist	Mid Slope	Other	None
Cradle Valley	CVKB04	411891	5389988	956	PCQ	8	160	RKP	Quartzite/Schist	Mid Slope	Other	None
Cradle Valley	CVPP01	412290	5391381	846	PCQ	28	190	RPP	Glacial till, Quartzite/Schist	Lower Slope	Other	None
Walls of Jerusalem	DKPP01	442547	5369072	1279	PCQ	18	130	RPP	Dolerite	Mid Slope	Other	None
Walls of Jerusalem	DKPP02	442490	5368992	1266	PCQ	10	150	RPP	Dolerite	Mid Slope	Other	None
Walls of Jerusalem	DKPP03	442374	5368914	1260	PCQ	4	120	RPP	Dolerite	Mid Slope	Other	None
Walls of Jerusalem	DKPP04	442345	5368649	1239	PCQ	7	130	RPP	Dolerite	Mid Slope	Other	None
Walls of Jerusalem	DKPP05	442828	5369050	1289	PCQ	15	220	RPW	Dolerite	Mid Slope	Talus slope	None
Walls of Jerusalem	DKPP06	442349	5368052	1177	PCQ	3	170	RPP	Dolerite	Lower Slope	Bog	None
Walls of Jerusalem	DKPP07	442158	5367901	1160	PCQ	12	210	RPP	Dolerite	Lower Slope	Other	None
Walls of Jerusalem	DKPP08	442321	5368157	1195	PCQ	5	160	RPP	Dolerite	Mid Slope	Other	None
Walls of Jerusalem	DKPP09	442301	5369227	1326	PCQ	12	170	RPP	Dolerite	Upper Slope	Other	None
Walls of Jerusalem	DKPP10	442085	5369183	1305	PCQ	5	140	RPP	Dolerite	Mid Slope	Other	None
Lake Mackenzie	LMPP01	449207	5386940	1142	PCQ	3	200	RPW	Dolerite	Lower Slope	Talus slope	None
Lake Mackenzie	LMPP02	449755	5387619	1147	PCQ	3	170	RPW	Dolerite	Mid Slope	Blockstream	Stags, scars
Lake Mackenzie	LMPP03	450197	5387561	1184	PCQ	10	190	RPP	Dolerite	Mid Slope	Other	None

APPENDIX 1 cont.

LOCATION	SITE	EASTING	NORTHING	ELEV[N]	PLOT TYPE	SLOPE	ASPECT	TASVEG	GEOLOGY	POSITION	LAND-FORM	FIRE HISTORY
Lake Mackenzie	LMPP04	450079	5387112	1132	PCQ	5	190	RPP	Dolerite	Lower slope	Talus Slope	Stags, Scars
Mount Anne	MACH01	452577	5243555	1230	10 x 10 m	18	40	HCH	Dolerite	Mid slope	Other	None
Mount Anne	MACH02	452493	5243564	1264	10 x 10 m	15	45	HCH	Dolerite	Upper slope	Other	None
Mount Anne	MACH03	452465	5243496	1282	10 x 10 m	10	30	HCH	Dolerite	Upper slope	Other	None
Mount Anne	MACH04	452420	5243465	1291	10 x 10 m	14	20	HCH	Dolerite	Ridge	Other	None
Mount Anne	MACH05	452637	5243858	1258	10 x 10 m	4	150	HCH	Dolerite	Ridge	Other	None
Mount Anne	MACH06	452708	5243792	1238	10 x 10 m	22	120	HCH	Dolerite	Upper slope	Other	None
Mount Anne	MACH07	452713	5243654	1207	10 x 10 m	2	140	HCH	Dolerite	Gully	Other	None
Mount Anne	MACH08	453262	5244467	1181	10 x 10 m	30	20	HCH	Dolerite	Mid slope	Talus Slope	None
Mount Anne	MACH09	453544	5244483	1095	10 x 10 m	5	20	HCH	Dolerite	Mid slope	Other	None
Mount Anne	MACH10	453628	5244507	1070	10 x 10 m	8	0	HCH	Dolerite	Mid slope	Other	None
Mount Anne	MACH11	455512	5243396	929	10 x 10 m	6	100	HCH	Glacial till	Gully	Other	None
Mount Anne	MACH12	455542	5243492	925	10 x 10 m	6	30	HCH/ MRR	Dolerite, glacial till, quartzite/schist	Upper slope	Other	None
Mount Anne	MACH13	455411	5243561	916	10 x 10 m	1	270	HCH	Glacial till	Flat	Bog	None
Mount Anne	MACH14	455273	5243393	930	10 x 10 m	8	180	HCH/ HHW	Glacial till	Lower slope	Other	None
Mount Anne	MACH15	455177	5243426	928	10 x 10 m	7	280	HCH	Glacial till	Upper slope	Other	None
Mount Anne	MAKB01	453963	5247185	780	PCQ	13	310	RKP	Limestone	Mid slope	Other	None
Mount Anne	MAKB02	454036	5247054	826	PCQ	25	310	RKP	Limestone	Mid slope	Other	None
Mount Anne	MAKB03	454094	5246895	892	PCQ	20	330	RKP	Limestone	Mid slope	Other	None
Mount Anne	MAKB04	454110	5246792	937	PCQ	25	355	RKP	Limestone	Upper slope	Other	None
Mount Anne	MAKB05	454329	5246470	1089	PCQ	5	160	RKS	Limestone	Ridge	Other	None
Mickeys Creek	MCPP01	473880	5377055	1226	PCQ	3	180	RPP	Dolerite	Mid slope	Talus Slope	Stags, scars
Mickeys Creek	MCPP02	474087	5376925	1210	PCQ	1		RPW/ RPP/ HHE	Dolerite	Flat	Bog	Stags, scars
Mickeys Creek	MCPP03	474990	5376917	1215	PCQ	5	200	RPW	Dolerite	Lower slope	Blockstream	Stags, scars
Mount Field	MFCH01	464485	5275568	1208	10 x 10 m	10	30	RPW	Dolerite	Lower slope	Talus Slope	None

APPENDIX 1 cont.

LOCATION	SITE	EASTING	NORTHING	ELEV^N	PLOT TYPE	SLOPE	ASPECT	TASVEG	GEOLOGY	POSITION	LAND-FORM	FIRE HISTORY
Mount Field	MFCH02	464907	5275048	1220	10 x 10 m	22	290	HCH	Dolerite	Mid slope	Talus slope	None
Mount Field	MFCH03	463972	5276825	1149	10 x 10 m	18	120	RPW	Dolerite	Lower slope	Talus slope	None
Mount Field	MFCH04	465834	5274021	1274	10 x 10 m	2	160	HCH	Dolerite	Flat	Other	None
Mount Field	MFCH05	465846	5273951	1274	10 x 10 m	1	160	HCH	Dolerite	Flat	Other	None
Mount Field	MFCH06	465965	5273327	1273	10 x 10 m	3	330	HCH	Dolerite	Upper slope	Other	None
Mount Field	MFCH07	465843	5273334	1251	10 x 10 m	6	190	HCH	Dolerite	Upper slope	Blockstream	None
Mount Field	MFCH08	465567	5274030	1290	10 x 10 m	5	320	HCH	Dolerite	Ridge	Other	None
Mount Field	MFCH09	465661	5274579	1242	10 x 10 m	1	40	HCH	Dolerite	Upper slope	Other	None
Mount Field	MFCH10	465801	5274601	1223	10 x 10 m	1	100	HCH	Dolerite	Mid slope	Other	None
Mount Field	MFPP01	464485	5275568	1208	PCQ	10	30	RPW	Dolerite	Lower slope	Talus slope	None
Mount Field	MFPP02	464384	5275691	1185	PCQ	15	280	RPW	Dolerite	Mid slope	Other	None
Mount Field	MFPP03	463972	5276825	1149	PCQ	18	120	RPW	Dolerite	Lower slope	Other	None
Mount Field	MFPP04	464119	5276795	1141	PCQ	15	250	RPW	Dolerite	Lower slope	Other	None
Mount Field	MFPP05	463992	5276074	1162	PCQ	12	30	RPF	Dolerite	Lower slope	Other	None
Mount Ironstone	MIPP01	457036	5383255	1239	PCQ	6		RPW	Dolerite	Mid slope	Blockstream	None
Mount Ironstone	MIPP02	457195	5383363	1229	PCQ	4	330	RPW	Dolerite	Mid slope	Blockstream	None
Mount Ironstone	MIPP03	457122	5383414	1223	PCQ	6	330	RPW	Dolerite	Mid slope	Blockstream	None
Mount Read	MRCH01	378708	5366156	1074	10 x 10 m	5		RKF	Mt Read volcanics	Upper slope	Other	None
Mount Read	MRCH02	378569	5366138	1070	10 x 10 m	8	100	HCH	Mt Read volcanics	Ridge	Other	None
Mount Read	MRKB01	378643	5365299	892	PCQ	4	220	RKF	Mt Read volcanics, quartzite	Upper slope	Other	None
Mount Read	MRKB02	377534	5366684	976	PCQ	8	280	RKP	Mt Read volcanics	Mid slope	Other	None
Mount Read	MRKB03	378624	5365577	910	PCQ	2	170	RKF	Mt Read volcanics	Gully	Other	None
Mount Read	MRKB04	378961	5366286	1099	PCQ	7	180	RKF	Mt Read volcanics	Upper slope	Other	None
Mount Read	MRKB05	377523	5366648	968	PCQ	13	230	RKP	Mt Read volcanics	Mid slope	Other	None
Mount Read	MRKB06	377709	5367451	963	PCQ	35	70	RKP	Mt Read volcanics	Ridge	Other	*Athrotaxis* stags

APPENDIX 1 cont.

LOCATION	SITE	EASTING	NORTHING	ELEV[N]	PLOT TYPE	SLOPE	ASPECT	TASVEG	GEOLOGY	POSITION	LAND-FORM	FIRE HISTORY
Mount Read	MRKB07	377590	5367316	947	PCQ	18	270	RKP	Mt Read volcanics	Upper slope	Other	*Athrotaxis* stags
Mount Read	MRKB08	377672	5367335	967	PCQ	35	290	RKP	Mt Read volcanics	Mid Slope	Other	*Athrotaxis* stags
Nive River	NRCH01	447397	5349114	910	50 x 2 m	0	298	SRI	Dolerite	Flat	Other	None
Pine Lake	PLPP01	475472	5378439	1195	PCQ	2	10	RPW	Dolerite	Lower slope	Blockstream	None
Pine Lake	PLPP02	475749	5378308	1185	PCQ	2	110	RPW	Dolerite	Flat	Blockstream	Stags, scars
Pine Lake	PLPP03	475029	5379090	1196	PCQ	3	95	RPP	Dolerite	Flat	Blockstream	None
Pine Lake	PLPP04	474947	5378989	1198	PCQ	4	110	RPW	Dolerite	Flat	Blockstream	Stags, Scars
Pine Lake	PLPP05	474817	5378880	1203	PCQ	8	80	RPP	Dolerite	Mid Slope	Blockstream	None
Pine Lake	PLPP06	475044	5378764	1195	PCQ	2	50	RPW	Dolerite	Flat	Bog	None
Winterbrook	WBKB01	414091	5410168	839	PCQ	18	40	RKP	Conglomerate	Mid Slope	Other	None
Winterbrook	WBKB02	414241	5410204	807	PCQ	15	70	RKP	Conglomerate	Mid Slope	Other	None
Winterbrook	WBKB03	414565	5410251	743	PCQ	30	310	RKP	Conglomerate	Mid Slope	Other	None
Winterbrook	WBKB04	414769	5410445	707	PCQ	8	320	RKP	Conglomerate	Mid Slope	Other	None
Winterbrook	WBKB05	414813	5410467	705	PCQ	7	350	RKP	Conglomerate	Mid Slope	Other	None
Winterbrook	WBKB06	416157	5411600	621	PCQ	0	0	RML	Conglomerate	Flat	Other	None

BIOLOGY, ECOLOGY AND VOLTINISM OF THE AUSTRALIAN SPONGILLAFLY *SISYRA PEDDERENSIS* SMITHERS (NEUROPTERA: SISYRIDAE)

by G. N. R. Forteath and A. W. Osborn

(with eight text-figures, eight plates and one table)

Forteath, G. N. R. & Osborn, A. W. 2012 (14:xii): Biology, ecology and voltinism of the Australian spongillafly *Sisyra pedderensis* Smithers (Neuroptera: Sisyridae). *Papers and Proceedings of the Royal Society of Tasmania* 146: 25–35. ISSN 0080-4703. Queen Victoria Museum and Art Gallery, PO Box 403, Launceston, Tasmania 7250, Australia (GNRF* AWO). *Author for correspondence. Email: forteath@dodo.com.au

The life stages of *Sisyra pedderensis* are described and statistical data from laboratory rearing experiments discussed. Novel sampling methods were used to obtain pupae from the field since adults were not attracted to black lights and the larval life cycle closed in the laboratory. The diel cycles of egg eclosion, full-fed larval emergence from aquatic habitats, and adult emergence are examined and illustrated. Morphological data are provided to identify the three larval instars. A comprehensive comparison of the biology of *S. pedderensis* and closely related overseas species is made. In Lake Pedder, this species of spongillafly was proved to be bivoltine, with overwintering larvae becoming imagines in early summer which was followed by a single summer generation.

Key Words: Aquatic lacewing, bionomics, bivoltine, limnology, Lake Pedder, Tasmania, natural science, *Sisyra pedderensis*, Neuroptera.

INTRODUCTION

In Australia, spongillaflies (Neuroptera: Sisyridae) are relatively uncommon insects although two genera, *Sisyra* (nine species) and *Sisyrina* (two species), have been recorded (Smithers 1973, New 2000, Smithers *et al.* 2008). However, knowledge of the biology and ecology of Australian spongillaflies is very limited, and descriptions of life cycles are based on species from overseas.

Sisyra pedderensis Smithers, 2008 (Smithers *et al.* 2008) is the only spongillafly to be recorded from Tasmania where it occurs in Lake Pedder, the shores of which range from Northings 5264680 and 5235000 and Eastings 416550 and 448280 (GDA 94). Lake Pedder is an oligotrophic water body in the southwest wilderness of Tasmania covering 235 km^2. The lake has been managed as a reservoir by Hydro Tasmania since 1972 and when at full capacity holds 3.3 km^3 of water. More detailed information on the formation of the present Lake Pedder may be found in Osborn *et al.* (2008) and Forteath & Osborn (2012).

We identified the presence of the larvae of *S. pedderensis* in the lake when collecting freshwater sponges, *Radiospongilla pedderensis* Osborn, Forteath & Stanisic, 2008, during the winter of 1996 (Osborn *et al.* 2008). Later, during summer surveys of the aquatic fauna within some sheltered bays, we found large numbers of spongillafly cocoons spun in a variety of habitats. Subsequently, adult sisyrids were collected by sweeping hand nets among riparian vegetation around these bays, especially among clumps of cutting grass, *Gahnia grandis* (Labill.) S.T. Blake. We also discovered oviposition sites on the ventral surface of the leaves of *G. grandis* as well as in cracks and crevices of dead wood overhanging or adjacent to the water's edge.

More detailed investigations into the biology of *S. pedderensis* both in the field and laboratory followed. These included studies on reproduction, longevity, growth and development, and dormancy. Tauber & Tauber (1978) and Clifford (1982) pointed out that these characteristics, when quantified by time, express information about the sum total of numerous biological processes and can conveniently be used to classify an insect's life cycle in terms of voltinism.

The aims of the study were, therefore: (1) to obtain meaningful biological and ecological data relating to an Australian species of sisyrid; (2) to make biological comparisons with overseas species; and (3) to interpret the life cycle of *Sisyra pedderensis* in terms of voltinism.

MATERIALS AND METHODS

Field sites

Sisyra pedderensis had been recorded at a number of sites around the shoreline of Lake Pedder (Smithers *et al.* 2008) and at Edgar Dam (43°01'47"S 146°20'57"E), a tarn which lies in close proximity to the southeastern end of the lake (fig. 1). An area of Starfish Inlet (42°51'55"S 146°00'E) was selected for field studies of the terrestrial stages of the life cycle and the shallow water along the shoreline of Sprent Basin (42°46'03"S 145°59'19"E) for the collection of larvae and their host sponge *R. pedderensis* (fig. 1).

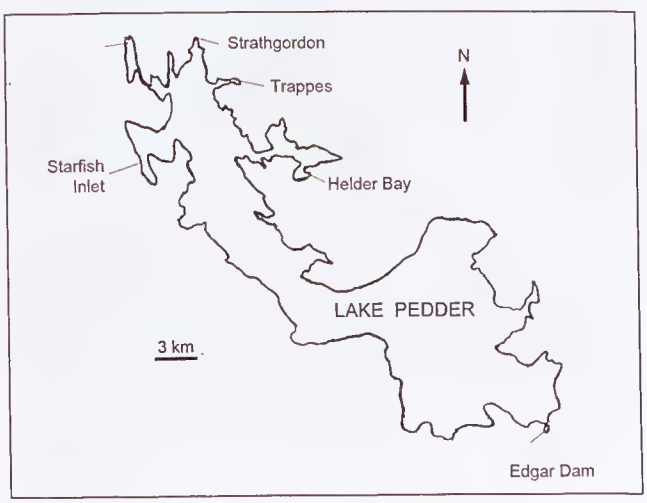

FIG. 1 — Map of sampling sites in Lake Pedder.

Osborn *et al.* (2008) noted a large number of freshwater sponges encrusting the flooded timbers and shrubs in Starfish Inlet. On sampling these sponges, we discovered that they were preyed upon by larval spongillaflies but the depth of water (3–4 m) greatly restricted their collection here. Furthermore, access to the bay was possible only by boat which made sampling in winter difficult. The bay was ideal, however, for the collection of migrating full-fed larvae, and cocoons which were abundant in the summer months on the aerial limbs of the flooded timber. Adult insects and their eggs were common also among the riparian vegetation.

Sprent Basin was accessible by road and many of the rocks strewn along the shallows of the western shore were encrusted with sponges in water no more than 60–80 cm deep. These sponges were preyed upon by spongillafly larvae. This bay, therefore, had the advantage that both the larvae of *S. pedderensis* and their host sponges were able to be sampled all year round by wading out from the shore and picking up suitable rocks.

Ambient air temperatures were recorded at the Tasmanian Weather Bureau's weather station at Strathgordon and the water temperatures of Lake Pedder by a data-logger anchored I m below the water surface (fig. 2).

We collected cocoons for our laboratory cultures. Prising cocoons from fissures along the aerial limbs of flooded timbers was time-consuming and often resulted in physical damage to the enclosed pupae, so we wrapped hessian sacks (80 cm × 35 cm) around tree trunks to act as artificial collectors (pl. 1). These were positioned 30–60 cm above the water surface of the lake using wool-bag staples. Each batch of sacks was left undisturbed for up to 14 days before being collected and replaced. On removal from the trees, the sacks were transported back to the laboratory and the cocoons individually harvested by snipping the surrounding hessian with scissors. Each cocoon was isolated in a 70 ml Perspex medical container up to the time the imago emerged.

The diel cycle of migrating full-fed larvae was studied in a similar manner by fixing sack-collectors around the aerial trunks of submerged trees. Twelve collectors were positioned 30 cm above the water surface and replaced every three hours over a 24-hour period. The larvae present on the sacks after each interval were transferred singly into a 70 ml container and observed until each had pupated.

Fifteen sack-collectors were deployed around suitable tree trunks in Starfish Inlet from early March to the end of April 2006 after which they were collected and the cocoons on them examined for overwintering prepupae. In addition, we collected cocoons in late March from aerial trunks and branches of submerged trees in Helder Bay (42°51'58.21"S 146°07'55.65"E), Trappes (42°48'05.10"S 146°05'18.76"E), and from under the bark of peppermint gums, *Eucalyptus nitida* Hook. f. root stocks of *Leptospermum lanigerum* (Sol. ex Aiton), and among tussocks of *G. grandis* along the shore of Sprent Basin.

Light traps (8-watt black light fluorescent tubes) failed to attract the imagines of *S. pedderensis*. Therefore, adult insects of both sexes were collected during the day and night using hand-nets and specimen jars. Specimens were stored immediately in 70% ethanol and later dissected to reveal their gut contents.

To attract oviposition, nine wooden gates made from staves 125 cm × 2.5 cm × 2.5 cm each consisting of two vertical bars supporting three horizontal bars, and three pontoons each constructed from three weathered wooden fence palings 160 cm × 13 cm × 1.5 cm and placed end to end, were positioned at right angles to the shoreline of Starfish Inlet (42°51'59.40"S 146°00'24.06"E) when imagines were flying in January. Three gates were placed on the bank of the lake within 1 m of the water's edge, three in the water 1 m from the shore and the remaining three in water 10 m from the shore. The horizontal bars were situated 10 cm, 20 cm and 30 cm above the ground or water, respectively. The first section of each of the three pontoons was placed on the shore and the remaining two moored over the water. The height of the pontoon above the ground and water was 10 cm. These structures were left in place for 14 days.

All clusters of eggs were counted on the pontoons. However, clusters were so numerous on the staves that three × 25 cm^2 sub-samples were counted on each surface of each stake.

Larvae were collected at regular intervals from Sprent Basin and a method of identifying the three larval instars of *S. pedderensis* was developed based on external morphological features using both light and scanning electron microscopy.

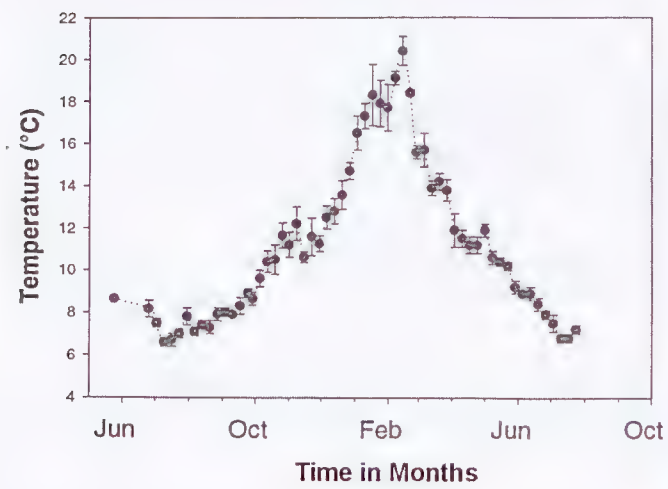

FIG. 2 — Mean water temperature profiles recorded over three years at a depth of 1 m in Lake Pedder.

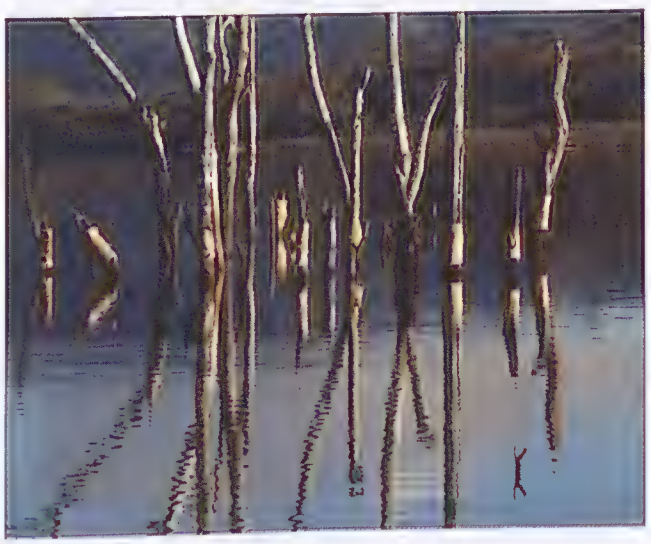

PLATE 1

Hessian sacks wrapped around tree trunks provide habitat for the construction of Sisyra pedderensis *cocoons.*

Laboratory

Cocoons and imagines were held under conditions of natural light and seasonal day length at an ambient temperature of 20°C; this being similar to the ambient air temperature at Lake Pedder in midsummer.

The suitability of several cage designs for keeping pairs of imagines were trialled. Pairs kept in modified 70 ml Perspex medical sample jars and fed sucrose syrup (100 g water:200 g sucrose), were found to have the greatest longevity. These jars were modified as follows:

- Sufficient BlueTac™ adhesive was placed on the inside of the lid to support the shaft of a golf-tee, while the cup end served as a food receptacle.
- A small hole was drilled in the end opposite the lid and a length of wire inserted through it which supported a small block of wood cut from a well-fissured fence paling (2 cm × 1.5 cm × 1 cm). The block was suspended a short distance above the golf-tee and acted as a roost for the pair by day and an oviposition site for the ♀ by night. The wooden blocks were harvested and replaced daily.

Pairs of virgin ♂ x ♀ imagines placed in these modified containers were used to study courtship, mating, longevity and fecundity.

Eggs were counted by placing a block under a dissecting microscope while the hooked end of a medical splinter-remover was passed under the silk protecting the clusters of eggs. The eggs were then prised out from within the fissures.

Duration of egg development and period of larval eclosion were determined by hanging wooden blocks on which there were clusters of eggs of known age inside inverted 70-ml containers. The lids of the containers were replaced by Scotch Tape 310™, the oviposition sites now coming to lie directly above the adhesive surface of the tape. On eclosion, larvae dropped from the wooden block, and were trapped on the adhesive surface below. The diel cycle of eclosion was established by hourly changes of the Scotch Tape. During the period of eclosion, light readings were recorded using a Digital Instruments Lux Meter model: LX1010B.

We also placed 10 batches of eggs and 25 pupae of known age in a Waeco incubator set at 10°C to investigate the effects of temperature on the development period of these two life stages.

Life cycle in the laboratory

Cocoons were collected on sack-collectors during the last two weeks of November. The P_1 population of imagines selected for the trial consisted of 20 pairs of virgin ♂♂ x ♀♀, all of which emerged on the same night. Each pair was placed in a modified 70 ml container.

On the first morning that oviposition was present on at least 15 of the 20 blocks, 10 were affixed to a wire running above the length of the water surface of an aquarium. The remaining five were suspended inside inverted 70-ml containers, the lids being replaced by Scotch Tape. The latter served as controls to confirm the time and day of eclosion of this particular cohort of F_1 larvae.

F_1 larval instars were on-grown in an acrylic aquarium, 120 cm long × 42 cm wide × 56 cm high, filled with 250 L of habitat water from Sprent Basin and filtered using both a JEBO 819 rapid mechanical sand-filter and a trickle-filter which passed the water over a bed of activated charcoal. Both systems were turned off for a period of 24 hours during larval eclosion from the eggs to avoid possible mechanical injury to newly hatched larvae and/or interference to larval settlement from water currents from influent water. The filter systems also were timed to turn off one hour before sunset to one hour after sunrise once third instar larvae were identified on the sponges, to avoid damage to full-fed larvae migrating from the water.

Water temperature in the aquarium was held at a constant 18°C to correspond with the mean water temperature of Lake Pedder in January and early February (fig. 2).

To minimise growth of filamentous unicellular algae over the surface of the sponges, the amount of natural daylight entering the aquarium room was reduced and the sides of the tank covered by cardboard from its base to a height of 20 cm. Further shading was achieved through naturally occurring tannins in the habitat water. These measures reduced the light in the vicinity of the sponges to ≤100 Lux.

Dissolved oxygen concentrations in the water were monitored daily using an Oxy-Tech Dissolved Oxygen Meter, and both total ammonia and pH of the water determined by the use of Merck water quality test kits.

Thirty green sponges, *Radiospongilla pedderensis*, were collected from Sprent Basin during the second week of December, each sponge encrusting the upper surface of a single rock approximately 8 cm × 4 cm. Before these were placed in the aquarium, they were examined under a microscope for the presence and removal of any spongillafly larvae. The sponge-encrusted rocks were then placed on the bottom of the aquarium in three clusters of 10 rocks each, the sponges facing towards the water surface.

A single sponge from each of the three rock clusters was inspected one day after the eggs hatched to confirm larval settlement, and a further sample taken on day 20 in order to monitor the progress of larval development.

Once third instar larvae were observed, each rock cluster was encircled by three lengths of fence paling, each 80 cm × 10 cm × 1.5 cm which were weighted down by ceramic insulators. On being lowered over each rock cluster they formed a tepee-like structure. Hessian sacks were wrapped around each length of paling rising above the waterline. Thereafter, both palings and sacks were examined each morning for cocoons. Both the palings and sacks were replaced daily once the first batch of cocoons was observed.

Three days after larval emergence from the water ceased, the sponges were removed and examined under the microscope for any remaining larvae.

The F_1 cocoons were harvested and placed individually in containers. On emergence of the imagines, 15 virgin ♂♂ and 15 virgin ♀♀ were paired and each pair placed in a rearing container. The eggs laid each night were pooled into cohorts and on eclosion the F_2 larvae were trapped on Scotch Tape and counted.

RESULTS

The collection of both cocoons and full-fed larvae from Starfish Inlet using sack-collectors was highly successful. Most collectors were found to have at least 20 cocoons spun on them and some attracted over 100. The first cocoons were present by the second week of November and numbers were observed to peak between the last week in November and second week of December. Thereafter, new cocoons were present up to mid-March.

Full-fed larvae were present on collectors during the latter half of November and early December. Forty-two

larvae were observed spinning cocoons on a batch of 15 sacks set overnight in the last week of November. The diel cycle of full-fed larvae leaving the lake is shown in figure 3. Some larvae started to leave the water before sunset but peak emergence was recorded between half an hour after sunset and midnight. Likewise some larvae continued to emerge for a short period after sunrise. Full-fed larvae lost their gills prior to leaving the water (pl. 2).

Larvae removed from the collectors commenced spinning their cocoons within an hour of being placed in a container and cocoons were completed within 10–12 hours. The prepupae metamorphosed into pupae 12–14 hours later.

No overwintering prepupae were found among the 173 cocoons examined on collectors retrieved at the end of April from Starfish Inlet. Imagines appeared to have emerged normally from 158 of these and a further nine contained mummified pharate adults. The remainder appeared empty and possibly had been parasitised by the parasitoid *Trichomalopsis sisyrae* Askew, 2010 (Forteath *et al.* 2010). At this time in the year we also failed to find prepupae in cocoons collected from the other widely-dispersed sampling sites at Helder, Trappes and Sprent Basin, respectively.

The crop and gut of adult insects collected in the field contained a clear fluid and a number of particles, possibly fungal spores. No pollen grains or fragments of arthropod cuticle were observed in the crop or gut when viewed under high-power light microscopy.

PLATE 2
Abdominal sternites of full-fed Sisyra pedderensis *larva after having shed gills (picture taken underwater before insect emerged).*

Both the gates and pontoons successfully attracted oviposition (table 1). The clusters of eggs were particularly numerous on the lower surfaces of both types of structure while the upper surfaces were ignored completely. In total 85% of all oviposition sites observed on the gates (n= 5332) and 99.9% (n= 5709) on the pontoons were recorded on the lower surfaces and the remainder on the lateral surfaces. Gates placed 1 m from the shore attracted the greatest number of oviposition sites. Some eggs also were laid on the gates and sections of the pontoons placed on land.

The eggs of *S. pedderensis* have a mean length $\bar{x}$ = 0.3 mm S.E. ± 0.037 (n = 30) and have a small somewhat flattened micropyle with reticulation present over the chorion (pl. 3). These are laid in clusters of 1–14 eggs. At 20°C egg development was completed in 12 days whereas eggs incubated at 10°C required 30 days to hatch. The eggs hatched in the early morning as light intensity increased from 185 to 602 lux, i.e., about an hour either side of sunrise (fig. 4).

Larval identification

The three larval instars were identified using the following external morphological features:

First Instar (length: 0.2–0.4 mm)

The head is the broadest part of the body and is black. The antenna has five segments and basal segment broader and shorter than both second and third segments. The third is longer than the second. The fourth is narrower than the third. The fifth is narrow, acute, and has an apical seta. The third segment bears a distal spine running parallel with the fourth and fifth segments.

TABLE 1

***Sisyra pedderensis* egg clusters oviposited on horizontal surfaces of wooden gates and pontoons at Starfish Inlet over a two-week period in December 2007 and January 2008. (Counts on horizontal surfaces of gates were from sub-samples covering an area of 75 cm².)**

Distance from shore-line (M)	Height (cm) above sub-strate/water	Number of egg clusters on surfaces		
		Top	Bottom	Side × 2
Gates				
Land 1M	10	0	22	0
	20	0	4	0
	30	0	0	0
Water 1M	10	0	1429	461
	20	0	1170	256
	30	0	1440	37
Water 2M	10	0	259	4
	20	0	135	4
	30	0	110	0
Pontoons				
Land	10	0	475	26
0–1.67M	10	0	2127	6
1.67–3.2M	10	0	3058	10
	Total	0	10228	804

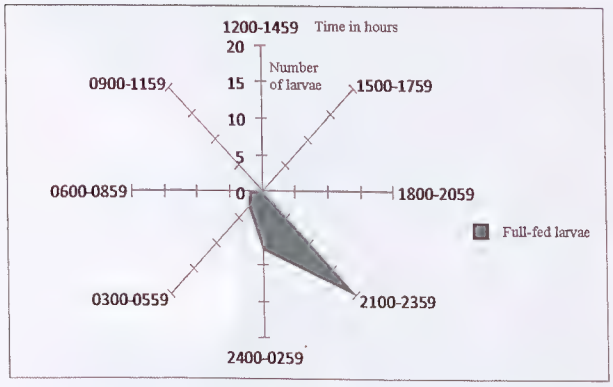

FIG. 3 — Number of full-fed Sisyra pedderensis *larvae leaving Lake Pedder in relation to time.*

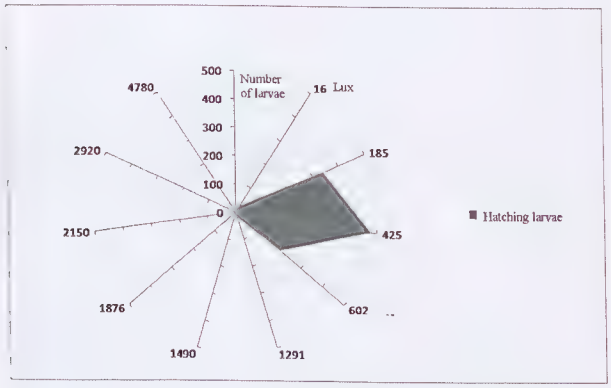

FIG. 4 — Number of larvae of Sisyra pedderensis *ecloding from eggs in relation to lux.*

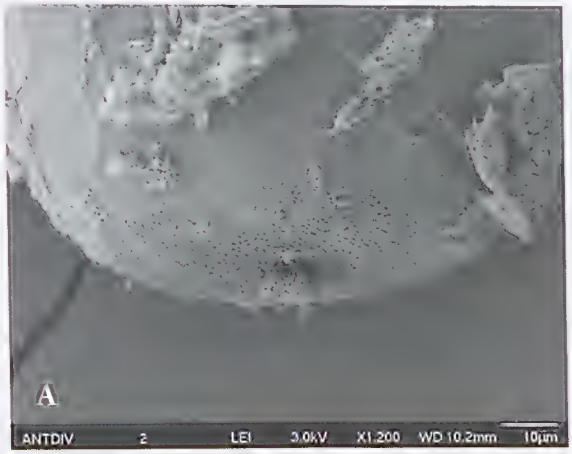

PLATE 3
(A) SEM image of the micropyle of Sisyra pedderensis *egg; and (B) SEM image of* S. pedderensis *egg showing reticulation on the chorion.*

PLATE 4
First instar Sisyra pedderensis *larva. Actual length: 0.3 mm.*

Pronotal collar absent. Lateral margins of the pro-, meso- and meta-nota darkly pigmented. The abdomen tapers towards the posterior and external gills are absent. Black setae are present on ninth and tenth abdominal segments (pl. 4).

Second Instar (length: 0.7–2.6 mm)

Width of head less than prothorax. The antenna has six segments. The second segment is the longest and the third shortest. The fourth is longer than the third and the fifth. The sixth is small and narrow. The fourth segment bears a distal seta which runs parallel to the fifth and extends to about 75% of the length of the sixth.

Pronotal collar present. Paired gills are present on the sternites of abdominal segments 1–7. Gills are three-segmented with a mid-dorsal ridge running the length of both the first and second gill segments (fig. 5).

Third Instar (length: 2.9–7.1 mm)

Mean head capsule width 0.424 mm S.E. ± 0.002 (n= 50) Antennae are greatly elongated, segments variable 11–14. The second segment is about three times the length of the third. Antepenultimate segment bears at its distal end a seta running parallel with penultimate segment. Two short setae are present on distal end of the terminal segment.

The pronotal collar is distinct. A pair of gills occurs on the first seven sternites of the abdominal segments (pl. 5). The first pair of gills is two-segmented and the remaining six are three- segmented. The basal segment of the first pair of gills is acutely angled about one-third from the distal end. The basal segments 2–5 are shaped like a boomerang, those of 6 and 7 are less curved. The second segment of gills on abdominal segments 2–7 arise ventrally from beneath the first segment.

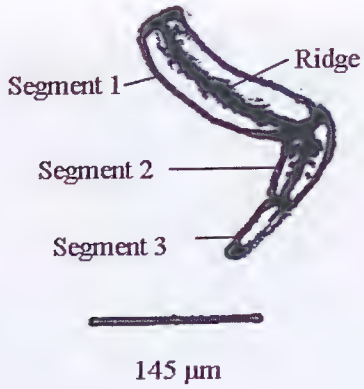

FIG. 5 — Sisyra pedderensis *second instar gill.*

PLATE 5

SEM image of third instar gills of Sisyra pedderensis *with diagrammatic inset illustrating numbers of segments.*

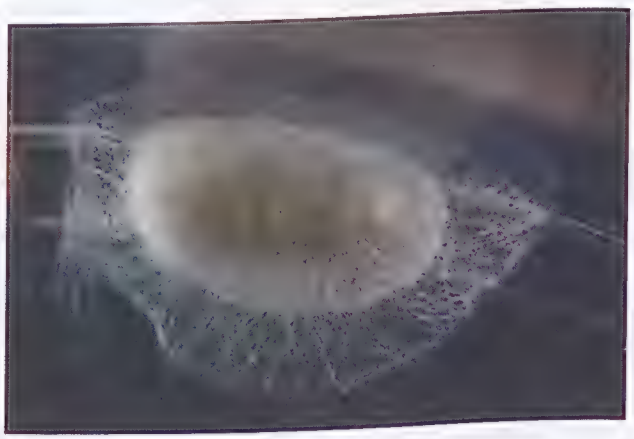

PLATE 6

A tightly spun Sisyra pedderensis *cocoon surrounded by a loose net of silk.*

Small third instar larvae, mean body length $\bar{x}$ = 3.8 mm S.E. ± 0.64 (n = 107) overwintered on sponges from April to October. Larvae increased in length in the spring, $\bar{x}$ = 6 mm S.E. ± 0.79 (n = 86) and become full-fed in November/December. All three larval instars were present on sponges in January, February and March, including large third instar larvae.

The cocoon consisted of an outer coarse mesh of silk spun over the top of a much finer, white oval shaped cocoon (length $\bar{x}$ = 3.7 mm S.E. ± 0.64 by width 2.6 mm S.E. ± 0.07 (n = 34) (pl. 6)). The exarate pupa was typically neuropteran, with head and terminal segments of the abdomen bent ventrally. The antennae pass over the head and come to lie along the front margins of the wings. The legs were drawn up towards the body. The third, fourth and fifth abdominal segments were ridged dorsally and bore a number of small sclerotised hooks.

At 20°C, emergence of the pupa occurred 10 days after the cocoon was spun. However, at 10°C the development period was extended to 20 days.

The pupa, on biting a hole in the cocoon, usually emerged completely before revealing the imago. Figure 6 illustrates the timing of adult emergences (n = 294). The newly emerged imago expanded its wings within 20 minutes and then deposited a faecal pellet. The majority of emergences usually occurred in the period one hour before and one hour after sunset, and emergence continued until after midnight. However, a not insignificant number of insects emerged in the four-hour period leading up to sunset. On heavily overcast days, there was often a 10-fold increase in the number of emergences recorded during this four-hour period. The ratio of male to female imagines was 1:1.

The majority of imagines mated after dark on the night following emergence. Under laboratory conditions typically both insects fed for several minutes and courtship, which rarely lasted for more than five to ten minutes, followed. Courtship involved raising of the wings followed by short, rapid darts over a substrate often in a circular direction. The male copulated laterally and a spermatophore, 750 µm in length, was transferred within three to five minutes. A few minutes after receiving the spermatophore the female was seen to bend her abdomen beneath her thorax and eat a portion of it (pl. 7a, b). Less than 1% of newly mated females oviposited on the night they mated.

In laboratory trials, ♀ imagines had a mean life expectancy of 14 days S.E. ± 3.36 while for ♂♂ $\bar{x}$ = 11.5 days S.E. ± 4.35 (n = 40) (fig. 7). The survival means between sexes were

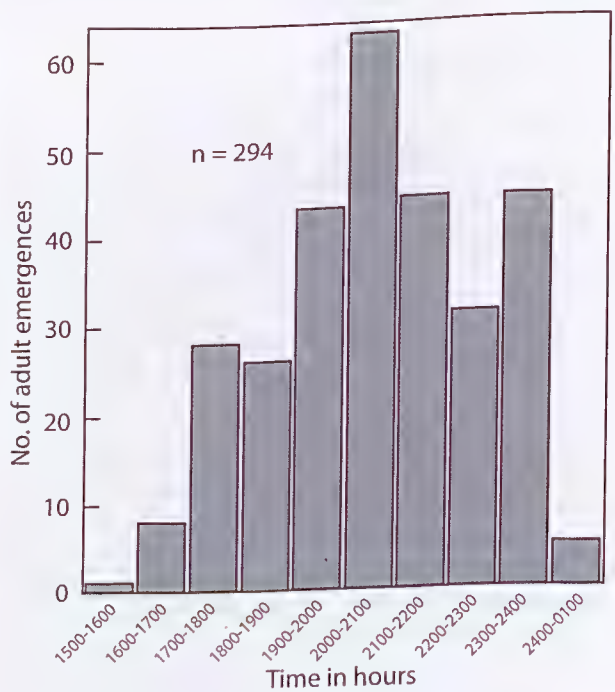

FIG. 6 — *Time of adult* Sisyra pedderensis *emergence.*

PLATE 7
(A) Female Sisyra pedderensis *imago with spermatophore. (B) A hole in a* S. pedderensis *spermatophore following feeding by the female.*

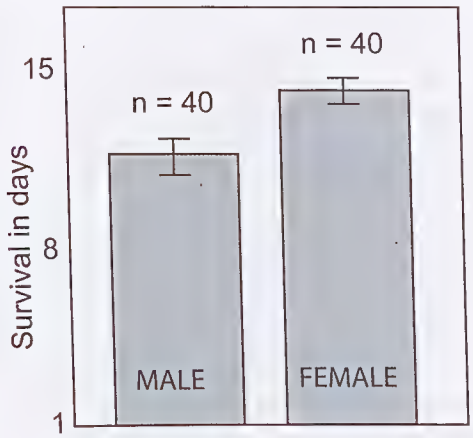

FIG. 7 — Mean survival in days of adult male and female Sisyra pedderensis *at 20°C (S.E. bars of means are shown).*

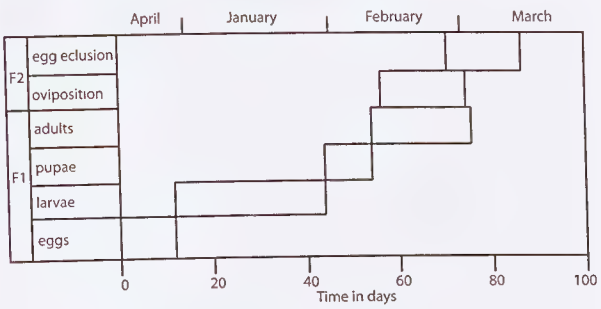

FIG. 8. — Summer life-cycle of Sisyra pedderensis *in Lake Pedder.*

significantly different t (78) = 2.9, p = 0.005. One ♀ lived for 28 days and one ♂ for 23 days. Oviposition was spread over an average of 11 nights S.E. ± 3.2, with a minimum of five and maximum of 19 nights, respectively, during which time ♀♀ oviposited on an average of seven nights S.E. ± 2.5. However, there was only a weak relationship between the number of nights a female oviposited and the number of eggs she produced (Pearson's r (correlation coefficient) = 0.4006; R^2 = 0.1604). Broods ranged from as few as 59 eggs to as many as 276 eggs. The greatest number of eggs oviposited by a ♀ on any one night was 140.

Closure of life cycle in the laboratory

Eggs were collected from P_1 imagines at the end of the first week of December. The F_1 larvae from a single cohort of eggs hatched at dawn 12 days later and larval settlement was confirmed the following morning. Third instar larvae were present on sponges 20 days after the eggs hatched.

A total of 184 full-fed larvae emerged from the water after dark and spun cocoons: 159 of these emerged 30 nights after eclosion, nine larvae 31 nights, and 16 larvae 32 nights, respectively. In total 85% of the cocoons were spun directly onto hessian sacks and the remainder in fissures on the palings. Imagines emerged after dark 10 days later. No larvae were found on the sponges following these emergences.

The life cycle of the F_1 cohort lasted a total 75 days, the last F_1 ♀ imago dying 21 days after emergence. In calendar months, the F_1 life cycle commenced in the second week of December and was completed in the first week of March. The 15 pairs of F_1 imagines gave rise to 18 cohorts of F_2 eggs from which a total of 818 larvae hatched. The first cohort of F_2 larvae hatched in the fourth week of February and the last at the end of the second week of March (fig. 8).

The 30 sponges collected as prey survived the length of the study and were not fouled by algae. The filtration systems were able to maintain water quality at levels considered suitable for fish culture ($NH_3 \leq 0.025$ ppm) and dissolved oxygen remained at saturation. A pH of 6.5 was recorded throughout the experiment. The water of Lake Pedder is acidic, having a pH range between 5.6 and 6.8.

DISCUSSION

Although nine species of *Sisyra* are known to occur in Australia (Smithers 1973, New 2000, Smithers *et al.* 2008), and one of these, *S. rufistigma* Tillyard, 1916 is considered to be conspecific in New Zealand (Wise 1998), their biology, ecology and life cycles are unknown. Furthermore, the larvae of most species have yet to be identified and described (Smithers 1973, Wise 1998). However, New (1992) stated sisyrids are reasonably common in Tasmania but gives no details.

The population of *S. pedderensis* in Lake Pedder possibly is unique in an Australian context in that both the aquatic and terrestrial life stages are locally abundant in many sheltered bays and inlets (Smithers *et al.* 2008). This probably is partially due to the widespread dispersal and successful settlement of their larval prey, *R. pedderensis*, on inundated timbers and shrubs during the flooding of the Serpentine Valley in the 1970s which resulted in the formation of the present lake (Osborn *et al.* 2008). An insight into the abundance of spongillaflies within our sampling area at Starfish Inlet is evident from both the large numbers of cocoons spun along the fissures of aerial

limbs of flooded timbers (pl. 8) and the many hundreds of ovipostion sites observed on the wooden gates and pontoons we placed at Starfish Inlet in January when imagines were on the wing.

Sampling techniques

Black lights were deployed to no avail on four separate nights when adults were on the wing at both Starfish and Trappes inlets. Therefore, being unable to attract imagines of *S. pedderensis* to ultraviolet lights we were effectively prevented from obtaining data on seasonal peaks and troughs in adult abundance in the field. However, sack-collectors proved an effective sampling method for the collection of meaningful data on the migration of the overwintering full-fed larvae from the lake and in confirming the absence of overwintering prepupae. This sampling method, however, was not effective in defining the summer generation of *S. pedderensis* since it was impossible to know whether the cocoons on the sacks in late December and early January were late cohorts of the overwintering generation or early cohorts of the summer generation. Confirmation of a summer generation was only possible by closing the life cycle in the laboratory.

Detailed early accounts of the biology and ecology of sisyrids are those given by Withycombe (1923, 1925), Killington (1936) and Brown (1952). Later Parfin & Gurney (1956) published a comprehensive review of the taxonomy, biology, sponge hosts and enemies of various species of Sisyridae with particular reference to the spongillaflies of the Western Hemisphere. Elliott (1977, 1996) gives a useful summary of the biology of *S. fuscata* Fabricius, 1793 and *S. terminalis* (Curtis,1854) based on these earlier studies by Withycombe (1923, 1925) and Killington (1936) and more recent work by Weissmair (1994), Weissmair & Waringer (1994). The results of our study on *S. pedderensis* not unexpectedly revealed the biology and ecology of this species have much in common with other species but there are noteworthy exceptions.

PLATE 8
Sisyra pedderensis *cocoons on an aerial trunk in Starfish Inlet.*

Life cycle

Oviposition

Spongillafly eggs usually are laid on the undersurface of leaves and branches overhanging water and on eclosion, the larvae fall directly onto the water below (Brown 1952, Weissmair 1994, Weissmair & Waringer 1994, Hölzel & Weissmair 2002, Rasmussen & Pescador 2002). In our study, oviposition sites were present in fissures only on the ventral and lateral surfaces of the wooden gates and pontoons in the field, and wooden blocks placed in the rearing containers in the laboratory. It seems that gravid females actively seek out surfaces on which to oviposit that will be shaded in daylight hours presumably to protect the developing embryos from desiccation and possibly drowning since exposed fissures fill with water in wet weather.

We also found oviposition sites on the ventral surfaces of *G. grandis* several metres from the water's edge. Likewise, oviposition sites were present in not insignificant numbers on those gates and sections of the pontoons placed on the banks of the lake. Pupedis (1986) discovered that the first instar larvae of *Climacia areolaris* (Hagen, 1861) were able to catapult themselves off a substrate. We do not know if newly hatched larvae of *S. pedderensis* have this ability but if proven it would provide them with a mechanism whereby they might reach the water when eggs were laid over land.

Egg development

Withycombe (1923) and Brown (1952) were able to show that temperature was an important controlling factor in the development of sisyrid eggs. The development time of 12 days at 20°C for the eggs of *S. pedderensis* is in keeping with those reported for other species incubated at similar temperatures (Withycombe 1923, Brown 1952, Parfin & Gurney 1956). However, the number of generations that *S. pedderensis* is able to complete annually at Lake Pedder may partially be controlled by the duration of the developmental period of both eggs and pupae. At 10°C, the development period of both these life stages was extended. It certainly is not unusual even in summer at this Tasmanian location to experience ambient air temperatures close to 10°C especially when low pressure fronts push north from the Southern Ocean.

Eclosion

Eclosion of spongillafly larvae from eggs usually occurs at night (Brown 1952, Pupedis 1986, Weissmair & Waringer 1994). Hatching of the larvae of *S. pedderensis,* on the other hand, was restricted to the period of first light at dawn. The larvae of *S. pedderensis* are demonstrably photo-negative, a behavioural trait which possibly enhances survival by forcing the newly hatched larvae down into the heavily tanninised water of Lake Pedder and away from increasing light intensity on the water surface as the sun rises. Weissmair (1994) noted that newly-hatched larvae of *S. fuscata* drifted for 24–168 hours depending on water temperature before settling on their sponge or bryozoan hosts. In the laboratory, we never observed the larvae to drift in the water column for more than an hour or two at most and the majority of larvae usually had settled on their prey within one hour of eclosion.

Larval morphology and identification

We developed simple morphological descriptions to allow us to identify the three larval instars of *S. pedderensis* based on keys and descriptions provided by Withycombe (1923), Parfin & Gurney (1956), Poirrier & Arceneaux (1972), Elliott (1996), Weissmair & Waringer (1994) and Rasmussen & Pescador (2002). Larval gills, in particular, have proved useful in differentiating between intra- and inter-larval instars (Poirrier & Arceneaux 1972, Elliott 1996, Weissmair & Waringer 1994, Rasmussen & Pescador 2002). The gills of second and third instars of *S. pedderensis* differ markedly and provide a useful morphological feature by which to tell them apart. It should be noted that the fourth segment of the antenna of the second instar of *S. pedderensis* bears a distal seta which runs parallel to the fifth segment and only part not all of the sixth segment as in *C. areolaris* (Parfin & Gurney, 1956). Parfin & Gurney (1956) have reviewed the reported body lengths of third instar larvae for several species: it appears that the body lengths of third instar larvae of *S. pedderensis* are slightly greater than those given by these researchers and Weissmair & Waringer (1994) and Elliott (1996) for *S. fuscata* and *S. terminalis*.

Diapause

It is apparent from sampling cocoons from diverse locations within Lake Pedder that *S. pedderensis* does not have a diapausing overwintering prepupal stage at this geographical location at least. The majority of larvae of *S. pedderensis* overwinter as small third instars preying on sponges.

Pupation

The majority of full-fed larvae of *S. pedderensis* migrated from the water to pupate at night; this behaviour being similar to that recorded for *C. areolaris* by Rasmussen & Pescador (2002). In Starfish Inlet cocoons were spun on the aerial limbs of flooded timbers sometimes less than a metre above the water surface. Along the western shore of Sprent Basin, however, where there were no flooded trees, cocoons were found up to 30 m from the water's edge under the bark of eucalypts, among exposed root-stocks of *L. lanigerum*, and tussocks of *G. grandis*, as well as in tangled mats of *Juncus articulatus* L. washed up along the shore. Several researchers have commented on the opportunistic nature of larvae when searching for suitable pupation sites (Withycombe 1923, Brown 1952, White 1976). The time taken to spin a cocoon by *S. pedderensis* appears to be similar to that reported by Needham & Betten (1901) for *S. vicaria* (Walker, 1853), and Withycombe (1923), Brown (1952) and Poirrier (1969) for *C. areolaris*. However, the prepupa of *S. pedderensis* undergoes metamorphosis to the pupal stage more rapidly.

Courtship and mating

Our observations on the courtship and mating behaviour of *S. pedderensis* are similar to those described for other species by Withycombe (1923), Brown (1952), Parfin & Gurney, (1956), Elliott (1977) and Pupedis (1987). However, in the laboratory mating by *S. pedderensis* usually occurred on the night after emergence. We never observed courtship or mating taking place later than this, whereas mating in both *C. areolaris* and *S. fuscata* is reported to occur a few hours to two weeks after emergence (Brown 1952, Elliott 1977). Brown (1952) collected imagines of *C. areolaris* copulating in flight on one occasion but we have no evidence of similar behaviour by *S. pedderensis*.

Feeding

In the wild, spongillafly imagines are reported to feed on pollen, aphids, plant mites, and even on the eggs of the alderfly *Sialis lutaria* Linnaeus, 1758 (Tjeder 1944, Brown 1952, Kokubu & Duelli 1983, Pupedis 1987, Monserrat 2005). Kokubu & Duelli (1983) and Stelzl (1991) found *S. terminalis* and *S. fuscata* also fed on honeydew to which was stuck various particles such as pollen grains, fungal spores and algae. Stelzl (1992) discussed the structure of the mouthparts of spongillaflies and suggested the modified lacinia were the principal organs for spooning up nectar while the grooved maxillary palps were used for catching small prey such as mites. The gut of *S. pedderensis* adults collected from the riparian vegetation at Starfish Inlet and Sprent Basin contained only clear fluid in which small particles, probably fungal spores, were embedded. We concluded these insects were feeding on honeydew.

Longevity of imagines

The longevity of spongillafly imagines in the wild is seldom reported but within a generation, adults appear to be on the wing for 4–6 weeks (White 1976, Andersen & Greve 1975, Elliott 1977, 1996, Weissmair 1994, Weissmair & Waringer 1994). In the laboratory, ♀♀ of *S. pedderensis* lived longer than ♂♂ but relatively few insects survived for more than 17 days. Brown (1952) managed to keep one insect alive for 21 days and we recorded a female surviving for 28 days. Oviposition was drawn out over as many as 19 nights but 11 on average, during which ♀♀ actually oviposited on an average of seven nights. A single generation of *S. pedderensis*, therefore, consists of a large number of cohorts and although longevity of individual insects may be short, each generation is on the wing for at least a month at Lake Pedder.

Clifford (1982), in a review of the life cycles of the Ephemeroptera, pointed out that it was not always clear what was meant by a cohort and suggested that ideally nymphs of the same cohort should all transform at or about the same time. Indeed this was found to be the case in our study. The larvae all hatched on the same morning, and emerged full-fed from the water to pupate over a relatively short period of three nights. Furthermore, no larvae remained on the sponges in the aquarium after this emergence period.

Voltinism

Research on spongillaflies shows that the more thoroughly a species is studied throughout its range, often the more flexible the life cycle is found to be. Withycombe (1923, 1925) for example offers circumstantial evidence to suggest *S. fuscata* is multivoltine but Killington (1936) and Andersen & Greve (1975) are more specific believing the species to be bivoltine. Killington (1936), Kimmins (1962), Weissmair (1994), Ellliott (1996) and Hölzel & Weissmair (2002) point out that at some locations *S. fuscata* has a complex life cycle which includes a diapausing winter generation of prepupae within cocoons and also a rapidly-developing summer generation. Langford (1975) deduced from the results he obtained from trapping imagines of *S. terminalis* in emergence traps along the banks of the River Severn in England that this species was univoltine, a view shared by Elliott (1996). In Austria, Weissmair (1994) and Hölzel & Weissmair (2002) reported *S. terminalis* to have a complex life cycle similar to that of *S. fuscata*. White (1976) found that *C. areolaris* had five distinct generations per year in Lake Texoma, Texas and Oklahoma, whereas Brown (1952) suggested three, possibly four, while in the State of New

York Needham & Betten (1901) considered the species to be bivoltine. White (1976) attributed these differences in voltinism of *C. areolaris* to climate, reflected in seasonal water temperature which would allow a longer growing season for sponges and consequently the production of more broods. At Lake Pedder, we suspect ambient air temperatures may exert a more immediate and tangible control on voltinism of *S. pedderensis* than the growth of *R. pedderensis* as this freshwater sponge is abundant throughout the year.

Studies on the voltinism of sisyrids have relied mostly on demonstrating peaks and troughs in abundance of imagines attracted to ultraviolet-blacklights (Tjeder 1944, Andersen & Greve 1975, White 1976, Kokubu & Duelli 1983, Weissmair 1994, Ramussen & Pescador 2002). Weissmair (1994) used both light-trapping and the laboratory rearing of eggs, larvae and adults to determine the number of generation of *S. fuscata* and *S. terminalis* in his studies. In our work, it has been necessary to close the life cycle of *S. pedderensis* in the laboratory to show that in Lake Pedder this species has a bivoltine winter-summer cycle; that is an overwintering generation in the larval stage and one summer generation in accordance with Clifford (1982).

Rearing techniques and developmental lengths

Benke *et al.* (1984) point out that some researchers feel that laboratory growth studies under "ideal" conditions result in development times that are shorter than actually occur in nature. For this reason we maintained the water temperature in our aquarium at 18°C to ensure it was similar to that recorded at Lake Pedder during the time the summer generation of larvae was expected to be present.

Likewise, many studies on aquatic insect larvae generally support the view that growth of a given species is sensitive to food quality and quantity (Clifford 1982, Chapman 1972, Aston 1973, Mackey 1976, Anderson & Cummins 1979, Milton Ward & Cummins 1979, Menzie, 1981, Benke *et al.* 1984, Campbell *et al.* 1998). Weissmair (1994) and Weissmair & Waringer (1994) point out that spongillafly larvae only colonise fully vital freshwater sponges. Other researchers have highlighted difficulties in rearing larvae on sponges due to the rapid mortality of the latter when fouled by algae (Withycombe 1923, Old 1933, Brown 1952). We endeavoured to maintain the quality of the prey by providing whole, undamaged sponges and reducing light intensity in the aquarium room to prevent the sponges becoming fouled by algae. The quantity of prey, on the other hand, was predetermined by the available surface area on which to place the sponges on the bottom of the aquarium and our preconceived surfaces on which to pupate. Thus we have no reason to believe the 30-day period of larval development in the aquarium to be dissimilar to that of larval development in Lake Pedder between late December and the end of February.

Generation lengths

Rapidly developing summer generations of *S. fuscata* have been reported by Killington (1936), Kimmins (1962) and Elliott, (1977, 1996) in England, and Weissmair (1994) and Hölzel & Weissmair (2002) have provided evidence of rapidly developing summer generations of both *S. fuscata* and *S. terminalis* in Austria. These summer generations were completed within about three months. From figure 8 it can be seen that the summer generation of *S. pedderensis* required two and a half months to complete under laboratory conditions. Eclosion of the F_2 larvae did not commence until the end of February with hatching of eggs continuing until mid-March. At Lake Pedder, both air and water temperatures are in decline from mid-March onwards and the development period of eggs must slow with many larvae not entering the water before April. Most of these larvae reach the third instar stage before the winter minimum water temperature. Weissmair (1994) and Hölzel & Weissmair (2002) found that larvae derived from eggs laid in summer (August) overwintered as first and second instar larvae in their study area in Austria, and Loru *et al.* (2005) established that *S. iridipennis* Costa, 1884 overwintered as first instars in NW Sardinia. Third instars of *S. pedderensis* do not become full-fed until November-December when water temperatures are again on the rise. These results show that *S. pedderensis* indeed has a bivoltine winter-summer life cycle in Lake Pedder.

To date, *S. pedderensis* has been found only in (a) Lake Pedder and (b) Edgar Dam. It remains to be seen whether the biology, ecology and bivoltine winter-summer life cycle of *S. pedderensis* described herein differ from other populations of as yet undiscovered populations or indeed other Australian sisyrids in general.

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REFERENCES

Andersen, T. & Greve, L. 1975: Neuroptera in light-traps at Osteroy, Hordaland. *Norwegian Entomologist* **22**: 12–128.

Anderson, N.H. & Cummins, K.W. 1979: Influences of diet on the life histories of aquatic insects. *Journal of the Fisheries Research Board of Canada* **36**: 335–342.

Aston, R.J. 1973: Field and experimental studies on the effects of a power station effluent on Tubificidae (Oligochaeta, Annelida). *Hydrobiologia* **42** (2-3): 225–242.

Benke, A.C., Van Arsdall, T.C., Gillespie, D.M. & Parish, F.K. 1984: Invertebrate productivity in a subtropical Blackwater River: the importance of habitat and life history. *Ecological Monographs* **54** (1): 25–63.

Brown, H.P. 1952: The life history of *Climacia areolaris* (Hagen), a neuropterous "parasite" of freshwater sponges. *American Midland Naturalist* **44**: 130–160.

Campbell, I.C., Parnrong, S. & Treadwell, S. 1998: Food availability and life history patterns of aquatic insects in evergreen eucalypt forest streams in Southwestern Australia. *Verhhandlung des Internationalen Verein Limnologie* **26**: 986–989.

Chapman, R.F. 1972: *The Insects, Structure and Function*. English University Press London: 819 pp.

Clifford, H.F. 1982: Life cycles of mayflies (Ephemeroptera), with special references to voltinism. *Quaestionnes Entomologicae*

18: 15–90.

Elliott, J.M. 1977: *A key to the Larvae and Adults of British Freshwater Megaloptera and Neuroptera with notes on their life cycles and ecology*. Freshwater Biological Association, Scientific Publication 35, Ambleside: 52 pp.

Elliott, J.M. 1996: *British Freshwater Megaloptera and Neuroptera: a key with ecological notes*. Freshwater Biological Association, Scientific Publication No. 54, Ambleside: 69 pp.

Forteath, G.N.R. & Osborn, A.W. 2012: Survival of endemic invertebrates of Lake Pedder and Lake Edgar subsequent to inundation. *Records of the Queen Victoria Museum* **116**: 26 pp.

Forteath, G.N.R., Osborn, A.W. & Askew, R.R. 2010: *Trichomalopsis sisyrae* Askew, Sp. Nov. (Hymenoptera: Pteromalidae) a parasitoid of *Sisyra* (Neuroptera: Sisyridae) in Tasmania, Australia. *Papers and Proceedings of the Royal Society of Tasmania* **144**: 15–19.

Hölzel, H. & Weissmair, W. 2002: Band 16. Insecta: Neuroptera. *In* Schwoerbel, J. & Zwick, P. Süsswasserfauna von Mitteleuropa. Band 15–17. Insecta: Megaloptera, Lepidoptera. *Spektrum Akademischer Veriag, Heidelberg-Berlin*: 31–38.

Killington, F.J. 1936: A monograph of British Neuroptera. *Ray Society, London* **1**: 306 pp.

Kimmins, D.E. 1962: *Keys to the British Species of Aquatic Megaloptera and Neuroptera with Ecological Notes*. Freshwater Biological Association, Scientific Publication Number 8, Ambleside: 21 pp.

Kokubu, H. & Duelli, P. 1983: Adult food of sponge flies: observations on the crop and gut content of *Sisyra terminalis* Curtis (Planipennia: Sisyridae). *Neuroptera International* **II** (3): 157–162.

Langford, T.E. 1975: The emergence of insects from a British river, warmed by power station cooling-water. *Hydrobiologia* **47**: 91–113.

Loru, L., Pantaleoni, R.A. & Sassu, A. 2005: Overwintering stages of *Sisyra iridipennis* A.Costa, 1884 (Neuroptera: Sisyridae). *Annali del Museo civico di Storia naturale di Ferrara* **8** (2007): 153–159.

Mackey, A.P. 1976: Quantitative studies of the Chironomidae (Diptera) of the River Thames and Kennet.11. The Flint Zone. *Archiv für Hydrobiologie* **78** (3): 310–318.

Menzie C.A. 1981: Ecology of *Cricotopus sylvestris* (Fabricius) (Diptera: Chironomidae) in a shallow estuarine cove. *Limnology and Oceanography* **26** (3): 467–481.

Milton Ward, G. & Cummins, K.W. 1979: Effects of food quality on growth of a stream detritivore, *Paretendipes albimanus* (Meigen) (Diptera: Chironomidae). *Ecology* **60** (1): 57–64.

Monserrat, V.J. 2005: Nuevos datos sobre algunas pequeñas familias de neurópteros (Insecta: Neuroptera: Nevrorthidae, Osmylidae, Sisyridae, Dilaridae). *Heteropterus Revista Entomologia* **5**: 1–26.

Needham, J.G. & Betten, C. 1901: Aquatic insects in the Adirondacks. *New York State Museum Bulletin* **47**: 383–612.

New, T.R. 1992: The lacewings (Insecta, Neuroptera) of Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* **126**: 29–45.

New, T.R. 2000: Neuroptera: *In* Naumann, I.D. (ed.): *The Insects of Australia*. Melbourne University Press: 1137 pp.

Old, M.C. 1933: Observations on the Sisyridae (Neuroptera): *Papers of the Michigan Academy of Science, Arts and Letters* **17**: 681–684.

Osborn, A.W., Forteath, G.N.R. & Stanisic, J. 2008: A new species of freshwater sponge (Porifera: Spongillidae) of the genus *Radiospongilla* from Lake Pedder in Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* **142** (2): 39–44.

Parfin, S.I. & Gurney, A.B. 1956: The spongilla-flies, with special reference to those of the Western Hemisphere (Sisyridae, Neuroptera). *Proceedings of the United States National Museum* **105**: 421–529.

Poirrier, M. 1969: Some fresh-water sponge hosts of Louisiana and Texas Spongilla-flies, with new locality records. *American Midland Naturalist* **81**: 573–575.

Poirrier, M. & Arceneaux, Y.M. 1972: Studies on the Southern Sisyridae (Spongilla-flies) with a key to the third-instar larvae and additional sponge-host records. *American Midland Naturalist* **88** (2): 455–458.

Pupedis, R.J. 1986: Hatching behaviour of sisyrid larvae (Neuroptera: Sisyridae). *Neuroptera International* **IV**(1): 53–55.

Pupedis, R.J. 1987: Foraging behavior and food of adult spongilla-flies (Neuroptera, Sisyridae). *Annals of the Entomological Society of America* **80** (6): 758–760.

Rasmussen, A. K. & Pescador, M.L. 2002: *A guide to the Magaloptera and Aquatic Neuroptera of Florida*. Florida Dept. of Environmental Protection Publication: 45 pp.

Smithers, C.N. 1973: A new species and new records of Sisyridae (Neuroptera) from Australia. *Australian Entomological Magazine* **1** (3): 19–21.

Smithers, C.N., Forteath, G.N.R. & Osborn, A.W. 2008: A new species of *Sisyra* Burmeister (Insecta: Neuroptera: Sisyridae) from Lake Pedder, Tasmania. *Australian Journal of Entomology* **47**: 77–79.

Stelzl, von M. 1991: Untersuchungen zu Nahrungsspektren mitteleuropaischer Neuropteren-Imagines (Neuropteroidea; Insecta). *Journal of Applied Entomology* **111**: 469–477.

Stelzl, M. 1992: Comparative studies on mouthparts and feeding habits of adult Raphidioptera and Neuroptera (Insecta: Neuropteroidea). *Proceedings of the Fourth International Symposium of Neuropterology* 341–347.

Tauber, M.J. & Tauber, C.A. 1978: Evolution of phenological strategies in insects: a comparative approach with eco-physiological and genetic considerations pp. 53-71. *In* H. Dingle (ed.): *Evolution of Insect Migration and Diapause*. Springer-Verlag, New York: 284 pp.

Tjeder, B. 1944: A note on the food of the adult *Sisyra fuscata* Fabricius (Neuroptera: Sisyridae). *Entomologisk Tidskrift* **65**: 203–204.

Weissmair, W. 1994: Eidonomie und Okologie zweier europaischer Schwammfliegen-Arten (Neuroptera: Sisyridae). *Entomologia Generalis* **18** (3/4): 261–272.

Weissmair, W. & Waringer, J. 1994: Identification of the larvae and pupae of *Sisyra fuscata* (Fabricius) and *Sisyra terminalis* Curtis, 1854, (Insecta: Planipennia: Sisyridae), based on Austrian material, Aquatic Insects. *International Journal of Freshwater Entomology* **16** (3): 147–155.

White, D.S. 1976: *Climacia areolaris* (Neuroptera: Sisyridae) in Lake Texoma, Texas, Oklahoma. *Entomological News, Philadelphia* **87**: 287–291.

Wise, K.A.J. 1998: A species of the family Sisyridae (Insecta: Neuroptera) in New Zealand. *New Zealand Entomologist* **21**: 11–16.

Withycombe, C.L. 1923: Notes on the biology of some British Neuroptera (Planipennia). *Transactions of the Entomological Society of London* **1922**: 501–594.

Withycombe, C.L. 1925: Some aspects of the biology and morphology of Neuroptera. With special references to the immature stages and their possible phylogenetic significance. *Transactions of the Entomological Society of London* **1924**: 303–401.

(accepted 2 September 2012)

MERTZ IN HOBART: IMPRESSIONS OF ONE OF MAWSON'S MEN WHILE PREPARING FOR ANTARCTIC ADVENTURE

by Anna Lucas

(with four plates)

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The story of the Australasian Antarctic Expedition (AAE) 1911–1914 has often been told in many publications which also refer to the drama of the Far-Eastern Sledging Journey from which Mawson trudged back to base, arriving in a desperate condition after both his companions, Xavier Mertz and Belgrave Ninnis, had died. Sir Douglas Mawson's career is well documented but we know less about his team of men and their work. What do we know of Mertz? The literature repeatedly notes that he was Swiss, held a doctorate in law, was a ski champion, looked after the expedition's dogs and died, mysteriously, on that Far-Eastern Sledging Journey. Details of his death have stimulated much discussion. But what of his life? Born in Basel in1882, he was six months younger than Mawson. With Ninnis he sailed from London on the AAE's S.Y. *Aurora* and spent November 1911 in Hobart as the team made final preparations for their Antarctic expedition. This paper focuses on that month of new experiences for the Swiss member of Mawson's team, his impressions of Hobart, the city's response to Antarctic explorers, what has changed and what remains as it was then.

Key Words: Antarctic, dogs, expedition, Hobart, Mawson, Mertz, quarantine, Switzerland, wharf.

INTRODUCTION

When Mawson returned from the Australasian Antarctic Expedition (AAE) in 1914 he, with the help of the expedition's doctor, Archibald McLean, collated and edited individual accounts of AAE members to produce an informative, illustrated narrative of their experiences, published as *The Home of the Blizzard* (Mawson 1915). This preceded publication of the expedition's scientific reports and with fundraising intent, appealed to the general reader. It offered a comprehensive background to the involvement of all AAE members, including Xavier Mertz (pl. 1). Mawson spent long months planning and organising this expedition, agonising over funding yet driven by the scientific potential of unknown territory. As a geologist, based at the University of Adelaide, South Australia, and interested in glacial influence on rock formations, he had taken an opportunity to travel south with Ernest Shackleton's British Antarctic Expedition (BAE) 1907–1909 (Shackleton 1909), to make further observations. His experiences on that trip were to seed his lifelong fascination with Antarctica. Within two years he was planning his own venture, drawing on the expertise of scientists and other professionals in the polar network to which he had been inducted.

After returning from the BAE, Shackleton undertook a series of lecture tours in 1910 in America and Europe, including Switzerland. Xavier Mertz, a keen mountaineer and ski enthusiast, possibly attended the lecture that Shackleton delivered in Basel. Lantern slides and cinematography accompanied the talk (*National Zeitung* 1910) and whether inspired by this presentation or enthused by another prompt, Mertz applied in early 1911 to the London office made available by Shackleton for Mawson when the latter was making arrangements for the AAE. The Mertz application to Mawson listed his academic and sporting achievements; he had graduated with a doctorate in law with a thesis on

PLATE 1

Dr Xavier Mertz (1882–1913) prior to leaving on the Australasian Antarctic Expedition in 1911. Photographer unknown. Mawson (1911a) acknowledged receipt of a photograph of Mertz when in London. It is possibly a self-portrait. Image supplied by and reproduced with permission of the South Australian Museum (Mawson Collection).

patents from the University of Bern in 1907, had won a Swiss national ski championship in 1908 and had climbed several mountains, including Mt Blanc (~4800 m) in the Alps (Mertz 1911a). In his father's factory he had learnt the principles of trades such as metalwork and carpentry. He had attended a school for engineers and had served his obligatory time in the Swiss Army. With his older brother Viktor, an engineer, he had been groomed to take over the running of the factory. However, a family dispute, centred around the rather autocratic father, resulted in both sons leaving: Viktor for New York and Xavier for Antarctica. This expedition may have been, for the 28-year-old Xavier, one last chance for adventure before surrendering to the responsibilities of the family business.

Xavier Mertz did not return. Hypotheses examining possible causes of his death in Antarctica have been the subject of much debate in the literature and will be discussed only briefly as here the focus is on the life of Mertz and particularly the month he spent in Hobart prior to the AAE's departure from that city. Impressions he recorded in his diary and in his three letters to friends suggest that he was optimistically and enthusiastically engaged with his surroundings. His observations are made with a high level of interest and an understated humour.

PREPARATIONS FOR ANTARCTICA

Most of the men selected for the AAE were young science graduates from Australian and New Zealand universities. Others, like Frank Hurley the official photographer, were specialists in an associated field. Mertz was not a scientist but Mawson, seeing potential in his proactive approach and his all-rounder attributes, accepted him. His ice experience would be invaluable and his practical skills would complement those of the other men. Mertz was asked to source alpine gear, including ropes, crampons and ice axes (Mawson 1911a) from Swiss companies and was sent to learn techniques of using water sampling and sounding equipment at the leading oceanographic institute in Europe, in Monaco (Mawson 1911b). Oceanography was, in 1911, a relatively new science and an important component of Mawson's planned scientific program. The Prince of Monaco, a keen oceanographer who supported the ventures of several of his contemporaries (Carpine 2002), lent the AAE most items of essential equipment requested (Mawson 1911c), including sounding and dredging equipment, trawling nets, and water sampling bottles.

After arriving back in London in July 1911, Mertz joined the AAE's ship, recently purchased with funds that flowed from a newspaper appeal endorsed by Shackleton (*Daily Mail*, London 1911). The ship, S.Y. *Aurora*, was placed under the command of John King Davis who had been first officer on Shackleton's *Nimrod*. Mawson had observed Davis in action during the BAE and wanted him to captain the AAE's ship. Here Mertz met his travelling companion, the 24-year-old Lieutenant Belgrave Ninnis. This young career soldier had taken special leave from his regiment, then based in Mauritius, to join a polar expedition, as his surgeon father had done. Ninnis and another AAE member, aircraft mechanic Frank Bickerton, had been directed to undertake a course of instruction in surveying prior to the ship's departure from London (Haddelsey 2005). As the only non-sailors on board S.Y. *Aurora*, Mertz and Ninnis had, as their main duty on the outward voyage, the care of 48 Greenland sledge dogs. Neither had any expertise in this work, but for the lawyer Mertz and the soldier Ninnis, "dog handler" became their job description by default.

The ship sailed first to Cardiff for coal, to Cape Town for supplies and for repairs, then to Hobart. Dogs and men adapted, not always well, to conditions on board, from the extremes of tropical weather to near freezing temperatures in higher latitudes near the Kerguelen Islands to where the ship had sailed to take advantage of the westerly winds to Tasmania. Heavy seas washed some dogs overboard, others died from distemper. Pups were born but few survived. Mertz built shelters for the animals but powerful winds and the action of waves crashing over the deck dismantled these temporary constructions (Mertz 1911–1913a, b). An enthusiastic photographer, who in later months enjoyed excursions with the AAE's Frank Hurley, Mertz was able to indulge his hobby on board. He set up a darkroom for developing and printing his images which documented aspects of shipboard life in calmer periods. Just after leaving Cape Town, with Ninnis and three other men he took a lifeboat and rowed for some distance from the ship to photograph it at sea. The captain, often scathingly critical and always a little ambivalent about his two passengers, was pleased with their efforts (Davis 1911a). As novice seamen, they did not always meet his expectations, but on 30 September 1911 he wrote: "Mertz tried his hand at steering and I found him a first rate helmsman. He was at ease as soon as he understood what was to be done". They had few calm days; storms and high seas made the 38-day passage (27 September–4 November) from Cape Town to Hobart difficult for men and dogs (Mertz 1911c).

FIRST IMPRESSIONS OF HOBART

As they neared Tasmania, all hands were given tasks to improve the appearance of the ship before it arrived in port. Mertz and Ninnis painted masts and other woodwork (Davis 1911b). They worked as replacements for crew who fell ill towards the end of the voyage, oiling the engine and stoking the furnace (Mertz 1911–1913c). During the trip, both men kept a diary, a habit they continued for the duration of the expedition, recording impressions of their surroundings, their companions, the work and the weather. Mertz wrote in German and the excerpts quoted in this paper are translated from his letters to friends or from a typed transcript of his diary entries. The whereabouts of his original handwritten diary, despite various attempts by researchers to trace it, is unknown.

After the challenging voyage from Cape Town, everyone onboard S.Y. *Aurora* was impatient for landfall, for civilisation and the comforts of civilisation. As Captain Davis noted in his diary (1911c), the first anticipated point of contact would be potentially rewarding.

> *A 10/- sweep as to the time of the pilot boarding the ship has been got up in the ward room and someone stands to win £3/10/-. We are all in it and Ninnis is looking after the matter.*

With anticipation, Mertz recorded their approach to Tasmania:

> *At noon on 3 November we saw the first land, far faraway, a faint shimmer. Only after looking out for a long time was I able to recognise the land as land. Closer and closer came the Tasmanian coast, with quite beautiful mountains. Soon we caught sight of a*

> *ship, the first since Cape Town (Mertz 1911–1913d, 3 November 1911).*

Later, in a letter to friends he wrote:

> *Eucalyptus trees form open woodlands. Our laburnum trees and fir trees are nowhere to be found. The typical Tasmanian bush (understorey) with enormous tree ferns stretches to the sea ... interesting rock formations. (Mertz 1911d, December 1911, p. 2)*

The hilly terrain was a welcome sight for Mertz who loved the arduous ascents of alpine regions in his homeland, who had taken time to climb two mountains when in Cape Town and who had often climbed *Aurora's* main mast to the crow's nest where he sang, yodelled or just sat and contemplated the changing mood of the ocean.

As the ship made its way up the River Derwent towards Hobart on the afternoon of 4 November 1911, the pilot came on board. This was an important moment and Mertz noted that Harry Corner, the second engineer, won the sweep. Mawson, who had arrived in Hobart from Adelaide two days previously (*The Examiner* 1911), also boarded the ship in the stream, bringing with him newspapers and mail for Mertz and Ninnis who "had the doubtful pleasure" of accompanying 40 dogs to the Quarantine Station at Crayfish Point near Taroona instead of proceeding immediately to the Hobart docks (Mertz 1911d, December 1911 p. 3). The lifeboat was lowered, the dogs offloaded, and the men rowed to shore. On the second run the boat, overladen with dogs, crates of dog biscuits, men, hand luggage and blankets, sprang a leak. The dogs were put out to swim to shore, the men bailed furiously, rowed in as far as they could and dragged the boat the last few metres. Local people arrived to help secure the dogs and, with potential chaos averted, Mertz and Ninnis (who had received no communications for over a month – since Cape Town) were eager to sit and read the now sodden newspapers and personal letters. They read of an uprising in China, tensions between Germany, England and France, war between Turkey and Italy and a workers' strike in Sydney. That night they slept in the open with the dogs (Mertz 1911d). Mertz does not record what rations they had nor if the blankets dried, but though conditions were uncomfortable, they (and the dogs) had been conditioned to privation en route, especially on the Cape Town to Hobart leg of the voyage.

Next day the Chief Quarantine Officer, Mr T. Tabart, examined the dogs and briefed the men on regulations and expectations. The dogs were physically unfit after being for so long in such confined conditions and were in need of a more varied diet. Distemper, the contagious canine disease which had plagued them during the voyage, still threatened. When initial instructions had been given, Tabart drove Mertz and Ninnis into Hobart in his two-horse carriage. "First impressions could not be better" (Mertz 1911–1913e, 5 November 1911). "These waterways remind me of our Swiss lakes ... They are ideal for sailing" (Mertz 1911d, December 1911 p.5). The backdrop of Mount Wellington, the low-density housing and colourful gardens of late spring all impressed him. Hobart then was a city of 27 719 people (Census 1911), with substantial buildings, streets lit with electric lamps (Petrow 2002), trams (pl. 2), and an extensive port area to cater for shipping including exports of wool, minerals, timber, grains and fruit (Walch's Almanac 1912).

In Hobart they met again with Mawson and some of the early arrivals. The AAE had established an office, with Conrad Eitel as administrator, in the building then occupied by the Tasmanian Tourist Association, opposite the General Post Office on the corner of Macquarie and Elizabeth Streets. Later that day Mertz enjoyed the luxury of a hot soapy bath – the first since Cape Town – and worthy of a mention in his diary (Mertz 1911–1913e).

WORK AND PLAY IN HOBART

After spending a day in the city, Mertz and Ninnis were obliged to return to the Quarantine Station. Two dogs had died of distemper. Others had been isolated but, as an additional precaution, Tabart subjected those dogs to a disinfecting dip (*The Mercury* 1911a). He also prescribed a more nourishing diet: "Some boiled sheep paunches, liver greaves mixed with oatmeal once a day, fish once a day, boiled cabbages and meat once a week" (Tabart 1911, p. 1). The introduction of a varied diet was undoubtedly beneficial and appreciated by the dogs. However, it is now illegal in Tasmania to feed offal to dogs (DPIPWE 2011).

Arrangements had been made for the two dog handlers to stay at the Fitzpatricks' place nearby. It was in a shed away

PLATE 2
Elizabeth Street, Hobart c.1911. The clock tower of the General Post Office, opposite which the AAE maintained an office, can be seen mid-image. Photographer uncertain. Part of the collection of photographs compiled by Australian photographer E. W. Searle while working for J. W. Beattie in Hobart during 1911–1915. Image supplied by and reproduced with permission of the National Library of Australia.

from the main house – "a cow barn", according to Mertz (1911–1913f, 6–10 November 1911). Other expeditioners had been billeted closer to Hobart in homes or boarding houses so, with a touch of his sometimes sardonic humour or perhaps to mask his disappointment, Ninnis named this basic shelter *The Ritz*. Hannah Mornemont noted, when retracing the journey of her great-great-uncle Belgrave 89 years later, that spectacular views across the river could have compensated for the shed's lack of comfort (Mornement 2004). Mertz and Ninnis adapted to their surroundings and settled into their new routine, caring for the dogs, lazing on the beach or rigging a makeshift sail – and the Swiss flag – on the repaired lifeboat (now named Davis after S.Y. *Aurora's* captain) and making not always successful attempts to launch it. Their presence was not unnoticed. "The daughters of the community bring some diversion.... We have already been invited to the yacht club and to tennis." wrote Mertz (1911–1913g, 6–10 November 1911). Another day, as they brought the little boat in, an old man approached them, curious about the significance of their flag (pl. 3). He believed he knew the flags of all nations, but had never seen one with a white cross on a red background. When told it was the flag of Switzerland, he amused Mertz by demanding to know why the Swiss fleet or its merchant ships had not previously visited Hobart (Mertz 1911–1913 h). Switzerland at that time did not have any ships on the high seas, only on the lakes.

A bicycle was available for their use and they took it in turns to ride into the city. Trams ran from the city to Long Beach in Lower Sandy Bay then, and the men could have ridden to that point from Taroona and completed the journey by tram, but it is more likely that they continued the ride to the city. Mertz read the shipping column first in the daily newspapers to gain greater cognisance of the harbour traffic (Mertz 1911–1913i). Ships brought more of their supplies from Britain, Europe, the Australian mainland or from New Zealand. Fellow expeditioners arrived by ship or by train. There were plenty of opportunities during his month in Hobart for socialising and sightseeing. He mentions meeting a "Miss Hoob" (Shoobridge?), "Dr. Sprent" and "Sorrell" (Mertz 1911–1913j, 10 November–2 December 1911). As well as yachting and tennis, he and Ninnis were invited to golf, dances, picnics and family dinners. Also on his list were Mount Wellington and inland Tasmania. Some men took a dray part way up the mountain, from where they trekked to the summit (Madigan 2000). Mertz was invited to an evening picnic and, recalling the forest huts near the inland lakes, wrote in his diary: "I shall never forget that moonlit night" (Mertz 1911–1913k, 7–9 December 1911). Later in a letter to friends he describes kangaroos and tigers on the banks of a lake, venomous snakes slithering in the grass (Mertz 1911d). He may have seen a Tasmanian Tiger (thylacine) there; the species was not yet extinct and it is likely that the unusual wildlife of the region would have been discussed. Alternatively, this could have been a simplification of his experiences, because he later visited a Hobart zoo where he did see Tasmanian Tigers (Blake 1911a).

In the last two weeks before the AAE's departure, the most important work was on Queen's Pier where S.Y. *Aurora* was berthed. Yorkshireman Frank Wild, an Antarctic veteran, had already arrived to oversee the wharf operations in Hobart. Eric Webb, the magnetician, had arrived from New Zealand. Biologist and artist, C.T. Harrisson, lived in Hobart and was the only Tasmanian member of the expedition. Several men arrived from Sydney on S.S. *Paloona* (*The Argus* 1911a);

PLATE 3

The Swiss flag on the rowboat near the Quarantine Station south of Hobart where Mertz and Ninnis (pictured) spent some of their time caring for the expedition's dogs. Photographer: Xavier Mertz. Image supplied by and reproduced with permission of the South Australian Museum (Mawson Collection).

others came from Adelaide and Melbourne, crossing Bass Strait to Launceston on S.S. *Loongana* (*The Argus* 1911b), then completing the trip to Hobart by train. Ernest Joyce, who had accompanied Scott and Shackleton as dog trainer, came on the *Corinthic* from England to join the AAE (*The Mercury* 1911b). Joyce was held in high regard by his former co-workers, but after an imprudent drinking bout and other annoyances he was dismissed, perhaps unfairly, by Mawson (Riffenburgh 2011). Joyce visited the Quarantine Station where he spoke to Mertz about training dogs in Antarctica (Mertz 1911–1913l) and while details of this exchange are not recorded, Mertz, whose only experience with Greenland sledge dogs was that gained on the three-month voyage from London, would have appreciated his advice.

On the wharf, equipment and supplies had to be repacked, coded for the Macquarie Island base or the three (later two) Antarctic bases, and reloaded onto S.Y. *Aurora* or prepared for the chartered support ship S.S. *Toroa* that would later take the second contingent of men and additional supplies to Macquarie Island (administered by Tasmania since 1900) where a wireless relay station and a meteorological station were to be established. Horses brought carts laden with crates for the AAE to the wharf. "There are many horses in this country," observed Mertz, recalling his first road trip into Hobart and other sightings. "Butcher assistants gallop through the main streets of the town with the meat basket on their arm. Errand boys deliver their packets mounted on horseback" (1911d, December 1911, p. 5).

He met and worked with other expeditioners on the wharf. Though he was still not fluent in English, any disadvantage was overcome by his good-natured acceptance of the inevitable teasing and his willingness to contribute to the overall effort. "My mistakes in English are so bad that they make jokes without trying" he had written previously to his friends (Mertz 1911b, September 1911, p.11). One of his co-workers was Cecil Madigan, a University of Adelaide geology graduate, who had deferred his Rhodes Scholarship appointment at Oxford University in England to participate in the expedition, who had an understanding of German, and who later became a close friend.

The working arrangement on the wharf was that the expeditioners would repack in the sheds and that union members would load the ship. When one of the AAE men

inadvertently carried a case onboard, an argument broke out and the unionists threatened to strike. Fortunately for the expedition's already tight schedule, the dispute was resolved before the threat was carried out (The Mercury, 1911c). Some incidents on the wharf benefited those who were in the right place at the time, for example when a large case of walnuts broke open one day during wharf operations and a group of delighted youngsters nearby were able to scoop up the scattered windfall (*The Mercury* 1911d). Other food that had spoiled on the voyage from London had to be discarded (Madigan 2000).

The work continued: prefabricated huts for the bases arrived from Sydney; the motor boat and numerous crates were loaded. The aeroplane arrived; it was now wingless after a crash ended its test flight in Adelaide injuring the pilot and less severely his passenger, Frank Wild. Destined to have limited use as a motor sledge in Antarctica, it too was stowed on the crowded deck (Lucas *et al.* 2011). During those busy days, carpenters made necessary alterations to the ship, and people visited. Newspaper reporters interviewed Mawson, Davis, Wild, Mertz and others. The expeditioners' clothing was distributed and Madigan and Webb, two of the most serious of the scientists, attracted public attention by walking through the streets dressed in their Antarctic outfits to the Town Hall, where they entertained the audience with a clowning routine on stage, prior to Mawson giving his lecture (Madigan 2000). When S.Y. *Aurora* had to be repositioned with its bow facing seaward to facilitate departure, this feat was accomplished "with a great deal of shouting" by men hauling on opposite sets of ropes attached to bow and stern while a small steamer simultaneously gave encouraging nudges (*The Mercury* 1911e).

One day, while working on the wharf, Mertz was surprised to hear a man greet him in Swiss German. After speaking mostly English for several months – "only our dogs understand Schweitzerdeutsch" (Mertz 1911b, September 1911, p. 1) – he felt that the sound of his own response was strange. His compatriot was not from Basel, but from another Swiss canton, St Gallen, had spent almost four decades in Australia, and was Professor of Modern Languages (French and German) at the University of Tasmania (Mertz 1911d). Professor Hermann Ritz had also researched the languages of Tasmania's Indigenous people, and as a member of The Royal Society of Tasmania, had published papers on the subject (Ritz 1909, 1913). Recordings of Aboriginal singer Fanny Cochrane were made for his language studies, some at The Royal Society's rooms in 1899 (Jacques 2004). After meeting Mertz at the wharf, Ritz immediately invited him to lunch and later to his home. He gave Mertz a condensed history of Tasmania's colonisation, settlement, agriculture and indigenous people. Of all the people he met in Hobart, Mertz really enjoyed and later keenly missed the company of Ritz and his wife. It was an important meeting and propitious; after Mertz's death in Antarctica, Ritz would act as intermediary for the distraught Mertz family and the AAE administration. While Mertz was in Hobart this friendship offered a welcome opportunity to revert to a familiar language and cultural environment, but the dichotomous effect of the association was both an immediate salve to an occasional bout of homesickness and afterwards a catalyst to reactivate those same pangs.

On the streets of Hobart the AAE men were "to be found everywhere, especially in Elizabeth Street with strawberries and cream" (Mertz 1911–1913m). Some of the favourite haunts of the AAE men were city fruit shops. "In nearly every fruiterer's shop here there is a kind of little back parlour where you can sit and gorge this delicious pottage" (Ninnis 1911, cited by Riffenburgh 2011, p. 97). Here the seasonal abundance of strawberries was exploited without restraint. The men would have been aware that fresh produce would soon be replaced by tinned and dried food and by expedition rations.

With constant media coverage, as a collective the expeditioners had gained almost celebrity status and as the day of departure drew nearer, more official functions were attended. Mawson gave two lectures in the Town Hall under the auspices of The Royal Society of Tasmania (*The Mercury* 1911f). Bishop Mercer conducted a special service for the expedition at St. David's Cathedral, commenting on the courage and enterprise of the AAE (*The Mercury* 1911g). On the eve of departure, the Premier of Tasmania, Sir Elliott Lewis, and Lady Lewis hosted a celebratory farewell for the expedition at the museum, where all invitees were treated to more strawberries and cream (Madigan 2000). Mertz (1911d) noted reflectively that he had never eaten as many strawberries as he had during his month-long stay, but expedition members missed the Annual Strawberry Feast in Hobart that summer (*The Mercury* 1912).

DEPARTURE AND BRIEF RETURN

On Saturday afternoon, 2 December 1911, after lunching at Hadley's Orient Hotel in Murray Street (*The Mercury* 1911h), Mawson and some of the team boarded the heavily laden S.Y. *Aurora*, which left with great ceremony from Queen's Pier at 4:00 pm (*The Mercury* 1911i). As Frank Hurley, the expedition's official photographer documented the departure with cinematography, Mertz climbed into the rigging to record the event with his camera:

> *Observing an old seafaring tradition, the sailors threw their last money away. Only empty pockets bring luck at sea. People stood in great masses on the wharves … The Governor of Tasmania appeared, a band played, the ropes were let go. With innumerable cheers and a gun salute, the Aurora departed, surrounded by sailing boats, rowing boats, motorboats and an accompanying steamer.* (pl. 4) (Mertz 1911–1913n, 10 November–2 December, 1911)

The Governor, His Excellency Sir Harry Barron, summoned Harrisson just before departure, congratulated him on his appointment to the AAE and urged him, as the lone Tasmanian, to do his best for the State (Rossiter 2011). At the Quarantine Station Ninnis, assisted by Joyce, was waiting with the dogs to board the ship. The first officer, who had not seen them for a month, remarked on the difference in the dogs' appearance "all fat with beautiful coats" (Gray 1914, p. 2). Here, most of the escorting flotilla turned back to Hobart as S.Y. *Aurora*, with one half of Mawson's team on board, set its course for the open sea and Macquarie Island. One hundred years later, as part of the Antarctic Centennial Year 2011–2012, a re-enactment of this event featured the Australian Antarctic Division's icebreaker *Aurora Australis* leading a flotilla of smaller craft in a sailpast on the River Derwent while the Governor of Tasmania, the Honourable Peter Underwood AC, took a 19-gun salute (Killick 2011).

Before S.Y. *Aurora* departed from the Quarantine Station, Mertz transferred to the pilot's boat which took him back to Hobart. That evening, he was seated in the newly built

PLATE 4
A flotilla of smaller craft accompanied S.Y. Aurora on the River Derwent as the AAE left Hobart on 2 December 1911 bound for Macquarie Island and Antarctica. Frank Hurley's cinematograph is set up on the tripod at the stern. Photographer: Xavier Mertz. Image supplied by and reproduced with permission of the South Australian Museum (Mawson Collection).

Grand Empire Theatre in Macquarie Street where the musical comedy *Our Miss Gibbs* was a sold-out success (Mertz 1911–1913o, *The Mercury* 1911j). The days between the departure of S.Y. *Aurora* and S.S. *Toroa* were relaxed and offered a chance for more social activities. On one visit to his compatriot Ritz, he listened to gramophone recordings of Swiss yodelling. Fellow expeditioners were to note Mertz's propensity to burst into a spontaneous rendition of a yodelling favourite; this would both startle them and leave them bemused. Madigan later wrote of midnight on board S.Y. *Aurora* as the New Year of 1912 was welcomed "The relieving and relieved watches made a lot of noise, Mertz's yodel being pre-eminent" (Madigan 1912).

Mertz visited Beaumaris Zoo with Leslie Blake, the AAE geologist and cartographer who was to be stationed on Macquarie Island. They were accompanied by Miss Nita Pipe. At this zoo, privately owned by Mrs Mary Roberts in Sandy Bay Road, Battery Point, they saw five Tasmanian Tigers, (*Thylacinus cynocephalus* (Harris, 1808)) (Blake 1911b), possibly the "tigers" that Mertz referred to in his letter to friends (Mertz 1911d). As well as these marsupial tigers, this zoo, known for its extensive aviaries, kept Tasmanian Devils (*Sarcophilus harrisii* (Boitard, 1841)), Bennetts Wallabies (*Macropus rufogriseus* (Desmarest,1817)), Common Wombats (*Vombatus ursinus tasmaniensis* (Shaw, 1800)), and other animals (Guiler 1986). Mertz doesn't mention the zoo in his diary, nor in his letters, but he and Blake both signed the visitors' book (Roberts 1904–1921).

Five days after Mawson's departure, S.S. *Toroa* left Hobart to rendezvous with S.Y. *Aurora* at Macquarie Island, taking more live sheep, more stores and the second half of Mawson's team including a somewhat reluctant Mertz, wishing he could spend a few more days in Hobart (Mertz 1911–1913). Retrospectively, the poignancy of his last letter to his friends in Switzerland becomes apparent. Mertz wrote that he would not be able to write for more than a year and offered them a double *Prosit!* for two New Year celebrations (Mertz 1911d). Ever the patriot, he also wrote that he was taking the Swiss flag with him, intending to raise it at several places on the Antarctic continent (which he did). Also in his luggage was a Basler banner to use as a sledge flag, and a range of edible Swiss specialties that he would share with the AAE team when they celebrated Swiss Confederation Day with him in the remote hut at Commonwealth Bay (Mertz 1911–1913q). Later that same year on 6 October 1912, they celebrated his 30th birthday – his last.

SUBSEQUENT DEVELOPMENTS

In *The Home of the Blizzard*, Mawson (1915) fully described the Far-Eastern Sledging Journey on which his two companions Belgrave Ninnis and Xavier Mertz died. It was an observational and mapping exercise that went terribly wrong. He tells how, when Ninnis broke through an insubstantial snowbridge to fall to his death in the underlying and unfathomably deep crevasse, the main sledge, supplies and the strongest sledge dogs went down with him. Mawson and Mertz were stranded 300 miles (~482 km) from base, without adequate clothing or rations (Jacka & Jacka 2008). They started the return journey, Mertz died on the way and Mawson arrived at the main base at Commonwealth Bay alone (Mawson 1915). Speculation on the cause/s of the death of Mertz varied. McLean's initial diagnosis of colitis in 1913 was based on Mawson's description of symptoms (Jacka & Jacka 2008).

Subsequent medical research led to conjecture that ingestion of toxic levels of Vitamin A after eating the livers of the slaughtered dogs (Cleland & Southcott 1969, Southcott *et al.* 1971) may have been a significant causal factor in the rapid deterioration of his health. Other contributing causes could have been malnutrition, exposure and hypothermia. It has also been suggested that the psychological stress of losing Ninnis, whom he considered his best friend on the expedition, and the loss of the dogs including his favourite, Basilisk, to which he had become so attached, were additional considerations and that to dispatch the remaining dogs and to eat them would have induced more pronounced stress for Mertz, since Mawson's association with them had been considerably less in preceding months (Carrington-Smith 2005). When Tim Jarvis re-enacted that journey, his aim was to examine the feasibility of Mawson's almost incredible account of one man's survival against all odds – an account questioned by Mawson's detractors. Travelling in similar clothing with similar rations and shelter, Jarvis concluded that such a journey was possible and that Mawson's version of events could be validated (Jarvis 2008).

As soon as Mawson returned to the main base, minimal details of the deaths of Mertz and Ninnis were relayed via wireless to S.Y. *Aurora* (which had already left and which had a receiving but no transmitting function), to Macquarie Island and to authorities who notified the men's families. A summary of Mertz's early association with the AAE was published in a Hobart newspaper (*The Mercury* 1913). Those who had worked so closely with the two men during the previous year in Antarctica were shocked. That they "were really dead seemed beyond belief" (Laseron 1947, p. 200).

The Mertz family were desperate for details. At that time, February 1913, erratic wireless communication meant that any updates would be limited until Mawson returned to Australia. Professor Ritz communicated with the family explaining the logistical problems of the situation and sought information about any further developments from the AAE administration so that he could keep the family informed, even contacting the Prime Minister of Australia on their behalf (Ritz 1913). On his return from Antarctica in 1914, Mawson wrote to the parents of Mertz and later

visited them in Switzerland to give a personal account of their son's death (Mawson 1964).

Mertz had gained the respect of his fellow expeditioners. Initial impressions were recorded of the "foreignness" of Mertz (Laseron 1947, p. 22, Madigan 2000). Though mainly monolingual themselves, the men couldn't resist recording examples of his imperfect English. Their perception of him as "other" to their own experience was reinforced by his misuse of words, ungrammatical expressions, urbane demeanour with polite mannerisms, his yodelling and even, for them, his unusual name (Laseron 1947). The Southern Ocean and Antarctic ice were levelling influences, presenting testing conditions for all. Mertz did not suffer from sea-sickness and was an expert on ice, but more than these attributes, it was his affability and his conscientious approach to hard work that won their total acceptance and their deep respect. Their dual destiny and close friendship inextricably links the names of Mertz and Ninnis. Their names often appear in the same sentence, almost as one word, in many AAE accounts. Two glaciers near their places of death bear their respective names. Those who wintered at the main base for the second year in 1913 expressed their respect for the two men by erecting a memorial cross, with a plaque which reads:

> *Erected to commemorate the supreme sacrifice made by Lieut. B.E.S. Ninnis, R.F. and Dr. X. Mertz in the cause of science A.A.E. 1913.*

The cross is still standing at Cape Denison in Antarctica (Australian Antarctic Division 2012).

Most of the AAE personnel, e.g., Eric Webb, John Hunter, Cecil Madigan and Captain Davis, returned home to build successful careers. Frank Hurley, Frank Bickerton and Frank Wild continued a life of adventure. Other members of the expedition, Leslie Blake and Robert Bage, were killed during World War I, 1914–1918, and Dr Archibald McLean died shortly afterwards from the effects of that war (Laseron 1947, Medical Journal of Australia 1922). Charles T. Harrisson was drowned when the Commonwealth Fisheries vessel, F.I.S. *Endeavour*, on which he worked as a biologist, foundered off Macquarie Island in 1914 (Court of Marine Inquiry 1915). These men were remembered when, in a ceremony in Franklin Square, Hobart on Empire Day 1918, Mrs C. Harrisson laid a wreath "in memory of Dr. Mertz and other comrades of C.T. Harrisson" (*The Mercury* 1918).

The streetscapes of Hobart have changed since 1911, but many places visited by Mertz still stand. The General Post Office, the Tasmanian Museum and Art Gallery, the Town Hall, St David's Cathedral (now with a bell tower) and Hadley's Hotel are landmark buildings. The site of the Quarantine Station is now occupied by the Tasmanian Aquaculture and Fisheries Institute. The University of Tasmania relocated from the Domain to Sandy Bay and grew to incorporate other campuses (Davis 1990) but now has plans to return some activities to the Domain site. Shops and offices have replaced the building where the AAE had its office. Trams ceased to run along Macquarie and Elizabeth streets in the 1960s; a network of buses now services a wider area. The Grand Empire Theatre, built in 1910, was renamed the Prince of Wales Theatre but demolished in the 1980s (*The Examiner* 1910, *The Mercury* 1987) to be replaced by an office building. Beaumaris Zoo, after the death of owner Mrs Mary Roberts, was transferred to the Domain in 1923 and closed in 1937 (Guiler 1986). Queen's Pier, after a partial collapse, was demolished in the 1960s (Hudspeth & Scripps 2000) and the AAE's ship, S.Y. *Aurora*, after leaving Sydney with a cargo of coal bound for Iquique, Chile, disappeared without trace in 1917 (Moyser 1919).

Mertz may have been shielded from World War I by Switzerland's neutrality, but his father's death in 1916 and his older brother's continuing residence in America, would have obliged him to return to family responsibilities in Basel, if he had survived his adventure in Antarctica.

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REFERENCES

The Argus newspaper (Melbourne) 1911a: 24 November 1911, p.6; 1911b: 21 November 1911, p.6.

Australian Antarctic Division 2012: Australian Antarctic Data Centre, Antarctic Heritage Register. Online at: http://data.aad.gov.au/aadc/artefacts/display_artefact.cfm?artefact_id=665 (accessed 22 May 2012).

Antarctic Centennial Year 2011: Online at: www.antarcticcentennial.tas.gov.au/home (accessed 12 December 2011).

Blake, L. 1911: Personal Diary (unpublished manuscript). State Library of Victoria MS 9551 MSB 471: 1911a: 5 December 1911; 1911b: 5 December 1911.

Carpine, C. 2002: La pratique de l'océanographie au temps du Prince Albert Ier Monaco. Musée océanographique, Monaco: 331 pp.

Carrington-Smith, D. 2005: Mawson and Mertz: a re-evaluation of their ill-fated mapping journey during the 1911-1914 Australasian Antarctic Expedition. *Medical Journal of Australia* **183**: (11/12) 638–641.

Census 1911: In *Walch's Tasmanian Almanac for 1912*. J. Walch & Sons, Hobart.

Cleland, J.B. & Southcott, R.V. 1969: Hyper-vitaminosis A in the Antarctic in the Australasian Antarctic Expedition of 1911–1914: a possible explanation of the illnesses of Mertz and Mawson. *Medical Journal of Australia* **1**: 1337.

Court of Marine Inquiry 1915: Report of the Court of Marine Inquiry held at Melbourne on 20, 23, 27 and 28 April and 3 May 1915. F.I.S. Fisheries Investigation Steamship "*Endeavour*". National Archives of Australia, Canberra. Series No. A5522.

Daily Mail newspaper (London) 1911: 8 May 1911, p.9.

Davis, J.K. 1911: Personal diary (unpublished manuscript). State Library of Victoria, John King Davis Collection MS 8311

3232/5. 1911a: 3 October; 1911b: 30 October; 1911c: 26 October.

Davis, R. 1990: *Open to Talent. The Centenary History of the University of Tasmania 1890–1990.* The University of Tasmania, Sandy Bay, Tasmania: 256 pp.

DPIPWE (Department of Primary Industries, Parks, Water and Environment) 2011. Online at: www.dpiw.tas.gov.au/inter.nsf/webpages/cart-6sa36r?open#HydatidDiseaseinTasm (accessed 12 December 2011).

The Examiner newspaper (Launceston), 1910: 30 December, p.6; 1911: 3 November, p.7.

Gray, P. 1914: Antarctic Voyages 1911–1914. Unpublished typescript. Australian Antarctic Division, Kingston, Tasmania. [

Guiler, E.R. 1986: The Beaumaris Zoo in Hobart. *Papers and Proceedings of the Tasmanian Historical Research Association* **33**: 12–171.

Haddelsey, S. 2005: *Born Adventurer: The Life of Frank Bickerton.* Sutton Publishing Ltd., Stroud: 255 pp.

Hudspeth, A. & Scripps, L. 2000: *Capital Port: A History of the Marine Board of Hobart 1858–1997.* Hobart Ports Corporation Pty. Ltd, Hobart: 461 pp.

Jacka, F. & Jacka, E. (eds) 2008: *Mawson's Antarctic Diaries.* Allen & Unwin, Crows Nest: 414 pp.

Jacques, J. 2004. Passing the Torch: Commemorating the Songs of Fanny Cochrane Smith. *Proceedings of the 2004 IASPM Australia New Zealand Conference.* Online at: http://search.informit.com.au/fullText;dn=448098046811483;res=IELHSS (accessed 22 May 2012).

Jarvis, T. 2008: *Life and Death in Antarctica.* The Miegunyah Press, Melbourne: 239 pp.

Killick, D. 2011: *Tribute to Antarctic Hero.* Online at: www.themercury.com.au/article/2011/12/03/281621_todays-news.html (accessed 12 December 2011).

Laseron, C. 1947: *South with Mawson: Reminiscences of the Australasian Antarctic Expedition, 1911–1914.* The Australasian Publishing Co. Pty Ltd. in association with George C. Harrap & Co., Sydney and London: 223 pp.

Lucas, A., Henderson, C., Leane, E. & Kriwoken, L. 2011: A flight of the imagination: Mawson's Antarctic aeroplane. *The Polar Journal* 1 (1): 63–75.

Madigan, C. 1912. Personal diary (unpublished manuscript). Privately owned by Madigan family. 1 January 1912

Madigan, D. 2000. *Vixere Fortes; a Family Archive.* Kingston, Tasmania: Private publication: 392 pp.

Mawson, D. 1911a: Letter to X. Mertz, 30 May 1911. Mitchell Library, State Library New South Wales. ML MSS 171/13x.

Mawson, D. 1911b: Letter to Dr. Jules Richard, 17 May 1911. Archives du Musée océanographique de Monaco. Lettres du docteur Jules Richard, Mawson file.

Mawson, D. 1911c: Letter to Dr. Jules Richard, 12 June 1911. Archives du Musée océanographique de Monaco. Lettres du docteur Jules Richard, Mawson file.

Mawson, D. 1915: *The Home of the Blizzard: Being the Story of the Australasian Antarctic Expedition, 1911–1914.* Vol. 1 & 2. William Heinemann, London.

Mawson, P. 1964: *Mawson of the Antarctic: The life of Sir Douglas Mawson, F.R.S., O.B.E.* Longmans, London: 240 pp.

Medical Journal of Australia 1922: Obituary: Archibald Lang McLean. *Med. J. Aust.* (3 June): 619–621.

The Mercury newspaper (Hobart), 1911a: 7 November, p.4; 1911b: 25 November, p.8; 1911c: 25 November, p.8; 1911d: 27 November, p.6; 1911e: 30 November, p.6; 1911f: 28 November, p.6; 1911g: 27 November, p.6; 1911h: 2 December, p.5; 1911i: 4 December, p.5; 1911j: 4 December, p.3; 1912: 9 January, p.6; 1913: 27 February, p.5; 1918: 25 May, p.8; 1987: 10 September, p.20.

Mertz, X. Personal diary 1911–1913 (unpublished typescript). Mawson Collection, South Australian Museum, SP, a: 26–31 August 1911; b: 12–15 October 1911; c: 22 October–3 November 1911; d: 22 October–3 November 1911; e: 5 November 1911; f: 6–10 November 1911; g: 6–10 November 1911; h: 10 November–2 December 1911; i: 10 November–2 December 1911; j: 10 November–2 December 1911; k: 7–9 December 1911; l: 10 November–2 December 1911; m: 10 November–2 December 1911; n: 10 November–2 December 1911; o: 3–7 December 1911; p: 3–7 December 1911; q: 1 August 1912.

Mertz, X. 1911a: Application to D. Mawson (undated). Mawson Collection, South Australian Museum. 13 AAE.

Mertz, X. 1911b: Letter to friends, September 1911. Mawson Collection, South Australian Museum. MI 16.

Mertz, X. 1911c: Letter to friends, October 1911. Mawson Collection, South Australian Museum. MI 16.

Mertz, X. 1911d: Letter to friends, December 1911. Mawson Collection, South Australian Museum. MI 16.

Mornement, H. 2004: In the steps of my ancestor. *James Caird Society Journal* **2**: 23–35.

Moyser, A.E. 1919: Letter to Captain J.K. Davis, 6 March 1919. State Library of Victoria. MS 8311; 3231/4.

National Zeitung newspaper (Basel, Switzerland), 1910: 23 November 1910, p. 20.

Ninnis, B.E.S. 1911 (cited by B. Riffenburgh 2011). Diary entry 29 November 1911. Scott Polar Research Institute, Cambridge, England.

Petrow, S. 2002: Servicing the city: water, street lighting and trams in Hobart 1858–1914. In *Living & Working in Hobart: Historical Perspectives. Papers and Proceedings of the conference held by the Professional Historians Association (Tasmania) on 30 October 2002*: pp. 39–57.

Riffenburgh, B. 2011: *Aurora: Douglas Mawson and the Australasian Antarctic Expedition 1911-14.* The Erskine Press, Norwich: 525 pp.

Ritz, H.B. 1909: The speech of the Tasmanian Aborigines. *Papers and Proceedings of the Royal Society of Tasmania* 1909: 44–81.

Ritz, H.B. 1913: Notes on native words of the Oyster Bay tribe. *Papers and Proceedings of the Royal Society of Tasmania* 1913: 82–94.

Ritz, H.B. 1913: Letter to the Prime Minister of Australia. 11 September. University of Sydney Archives. Edgeworth David Papers. Series 7, P.11.

Roberts, M. 1904–1921: Beaumaris Zoo Visitors' Book, Sandy Bay. 5 December 1911. Tasmanian Archives and Heritage Collection, LINC Tasmania. NS823/1/17.

Rossiter, H. (ed.) 2011. *Mawson's Forgotten Men: the Antarctic Diaries of C.T. Harrisson 1911-1913.* Pier 9, Sydney: 299 pp.

Shackleton, E. (with H.R. Mill & T.W.E. David) 1909: *The Heart of the Antarctic.* Vols.1 & 2. William Heinemann, London.

Southcott, R.V., Chesterfield, N.J. & Lugg, D.J. 1971: Vitamin A content of the livers of huskies and some seals from Antarctic and subantarctic regions. *Medical Journal of Australia* 6 February: 311–313

Tabart, T. 1911: Report, 9 November 1911. Mitchell Library, State Library of New South Wales, Sydney. Microfilm CY 3581, ML MSS 171/17.

Walch's Tasmanian Almanac for 1912. J. Walch & Sons, Hobart: pp. 275–279.

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DREDGING UP MAWSON: IMPLICATIONS FOR THE GEOLOGY OF COASTAL EAST ANTARCTICA

by Elizabeth M. Truswell

(with seven text-figures and two plates)

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During the 1911–1914 Australasian Antarctic Expedition samples of bottom sediment were dredged from a wide sweep of coastline extending from the main base at Commonwealth Bay, to the western edge of the Shackleton Ice Shelf. An earlier study showed these sediments to contain palynomorphs recycled from eroding sedimentary sequences. High concentrations of Permian, Jurassic to Early Cretaceous, and Cenozoic microfossils were present in three regions of the continental shelf, namely, offshore from the Shackleton Ice Shelf, from Cape Carr and from close to the Mertz Glacier. The findings of the earlier study are re-evaluated in the light of new information concerning the bathymetry of sampled areas on the continental shelf, the sub-ice topography of ice shelves and the Antarctic interior, and of sedimentary processes controlling the movement of palynomorphs on the sea floor. Data from the vicinity of the Shackleton Ice Shelf raise the possibility of sourcing some recycled material through sub-ice connections with the deep Aurora Subglacial Basin of the interior. From the George V Basin, west of the Mertz Glacier, new echo-sounding data show the dredges collected lie mostly on the edge of a steep trough parallel to the coast. Previous suggestions that Jurassic to Cretaceous sequences there correlate with those of the Otway Basin on the Australian margin are corroborated by recent seismic reflection data showing thick rift and pre-rift sequences offshore from the Adélie and Wilkes coasts. The relationship of these sequences to putative Mesozoic sequences within the inland Wilkes Basin is uncertain. Limited studies suggest that recycled palynomorphs in continental shelf sediments may lie close to the sites of their original deposition.

Key Words: Antarctica, Mawson, dredging, palynomorphs, recycling, continental shelf, ice shelves.

INTRODUCTION

The Australasian Antarctic Expedition of 1911–1914, under the leadership of Dr (later Sir) Douglas Mawson made enormous contributions to understanding the science of the Southern Ocean and the coastal margin of a wide sweep of East Antarctica. These contributions encompassed oceanography and meteorology, biology, and, perhaps reflecting Mawson's own background and enthusiasms, a particularly wide range of studies into the geology of the coastal region.

The scientific reports from the expedition were published over the period 1918–1942, delays in publication resulting from a number of factors – the First World War, the Great Depression, a lack of funding and Mawson's other commitments. Reports on aspects of the geology were wide-ranging, including, *inter alia*, studies of the metamorphic rocks of Adélie Land (Stillwell 1918,1923), the dolerites of Horn Bluff (Browne 1923), the dolerites and granites of King George Land (Summers & Edwards 1940), a single meteorite (Bayley & Stllwell 1923) and a host of studies on suites of metamorphic, igneous and sedimentary rocks from the moraines at Cape Denison, in the vicinity of Commonwealth Bay, where the expedition's main base was established (e.g., Coulson 1925, Glastonbury 1940).

Significantly, the earliest of the geological reports to be published were those by Frank Stillwell, who was a member of the main base party at Commonwealth Bay. Stillwell had recently graduated in engineering and science from the University of Melbourne (see Hince 2012 for a biography). His reports on the *in situ* metamorphic rocks of Adélie Land, and of amphibolites in erratics in the moraines of Cape Denison appeared in 1918 and 1923. The other geological reports, published in the 1920s and 1940s, were written by academic geologists who were not members of the expedition. Mawson's own reports, on the narrative of the voyage, on sedimentary rocks collected by the expedition, and his extensive catalogue of all the rock specimens, did not appear until 1940.

While this plethora of reports constituted a major contribution to understanding the onshore geology of coastal East Antarctica, the other area in which substantial information of a geological nature was provided was through the soundings and dredgings made from the SY *Aurora* – a steam yacht built in 1876 primarily for whaling in Arctic seas. The area of the Antarctic coastline sampled from the *Aurora* extends from 146° E to 90° E longitude, from the main base near Cape Denison, to the quarters of the Western Party on the western edge of the Shackleton Ice Shelf (fig.1).

In 1982, the centenary of the birth of Douglas Mawson, I was able to obtain some 53 dredge samples recovered from the driver tubes in the taking of depth samples on all three Antarctic voyages of the *Aurora* (Truswell 1982). The samples were processed to recover palynomorphs (spores, pollen and dinoflagellate cysts) that have been recycled into these surficial, or essentially Recent, muds by the erosion of sedimentary sequences on the continent or on the continental shelf by glacial or submarine processes. The distribution of these palynomorphs proved to be a useful tool in suggesting the position, age and depositional environment of sedimentary sequences hidden beneath ice cover.

The purpose of the present paper is to re-evaluate the significance of the distribution of the recycled palynomorphs in the light of current information relating to the geology of the coastal margin of East Antarctica. Specifically, three questions might now be asked. First, how do the data fit with contemporary understanding of the bathymetry of the continental shelf? Second, can the data be reconciled with what is now known of the sub-ice geology of inland

FIG.1 — Extract from Mawson's (1914) map of the East Antarctic coastal region, showing location of the main base at Commonwealth Bay, the Western Base near the Shackleton Ice Shelf, plus the tracks of the three Antarctic cruises, and of overland traverses.

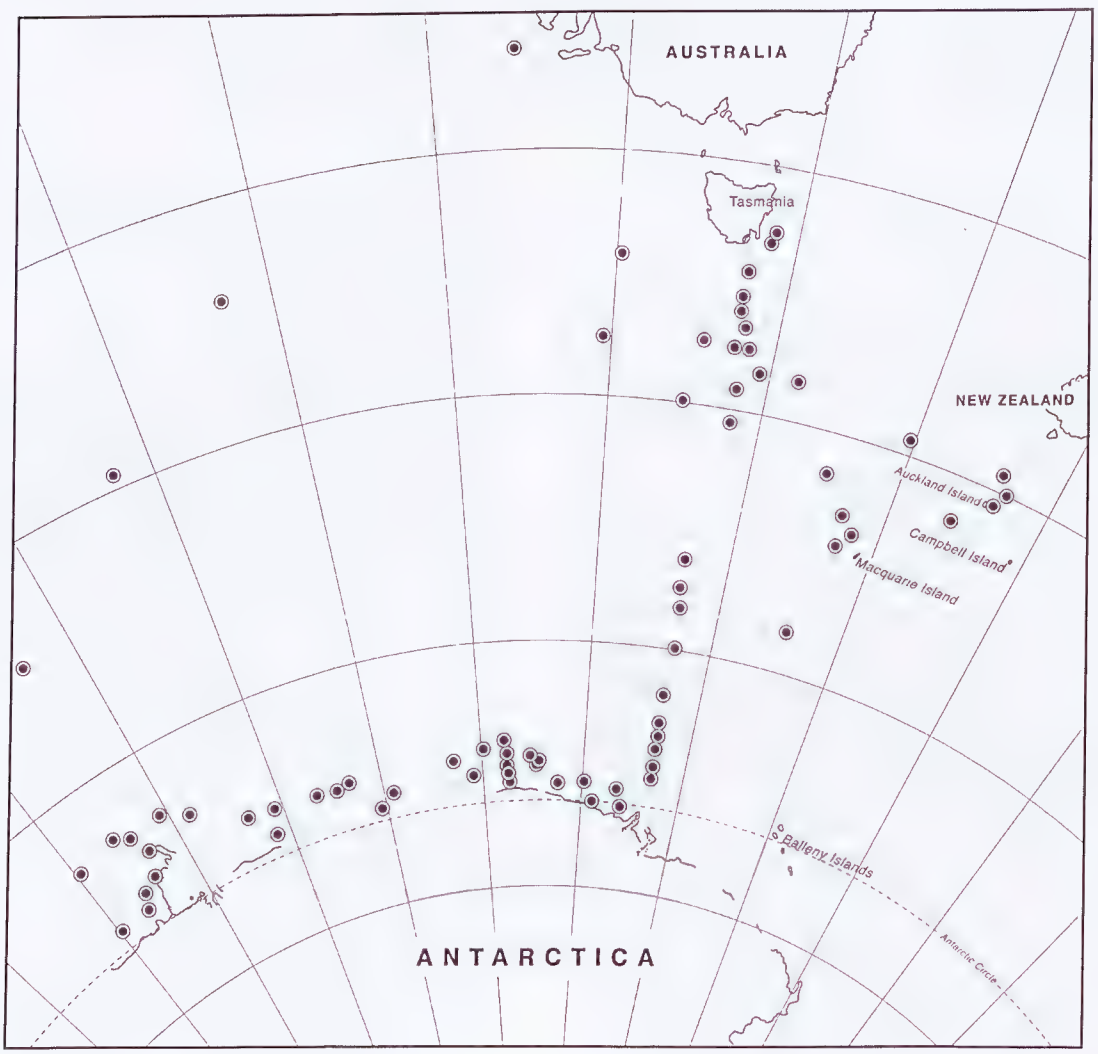

FIG. 2 — Southern Ocean showing location of soundings and dredgings on all Antarctic and sub-Antarctic cruises of the SY Aurora. *Simplified from Chapman (1922).*

Antarctica that impinges on the coast? Third, do we better understand the way in which these microfossils are moved around on the sea floor by sedimentary processes?

SOUNDINGS AND DREDGINGS

The operation of the deep-sea work of depth sounding and bottom sampling was carried out under the direction of Captain John King Davis FRGS, captain of the *Aurora*, and second-in-command of the expedition. In his report, published in 1939, Davis gave detailed descriptions of the types of machines employed by the ship's sounding party – a small band of crew members whom Davis described as "cheerful and energetic enthusiasts, ever ready for action, and reliable under the most trying conditions" (Davis 1939, p.91).

Depth soundings, and in many cases, sampling of bottom sediments, were carried out on all cruises of the Expedition, namely, the three Antarctic cruises, and two cruises in sub-Antarctic waters. The first cruise left Hobart in December 1911, but, owing to the crowded state of the decks of the *Aurora* on that first voyage, soundings were not taken until the ship neared the Antarctic coastline on 3 January 1912. Localities of the soundings are shown in figure 2. Davis reported that "The depth of the sea was obtained by one or other of two types of machine: for deepwater to depths of 6000 fathoms a Lucas sounding machine was employed; for depths of up to about 200 fathoms the Kelvin sounder was employed" (Davis 1939, p.91).

Two Lucas machines were used, one each on the port and starboard sides of the vessel. An example of the ready cooperation among explorers of this "heroic era" of Antarctic exploration is shown by the fact that a brass steam winding engine, used to wind in the wire on the port side sounder, was loaned to the party by Dr W.S. Bruce, leader of the 1902–1904 Scotia Expedition into Antarctic waters. The Lucas machine (pl. 1) consists of a central drum holding up to 6000 fathoms of tightly coiled wire passing out over a measuring wheel, where the length of wire, and hence the depth, is recorded directly on a clock-faced dial.

Where it was desirable to take samples of the sea floor, a driver, or hollow steel tube, was spliced on to the end of the sounding wire with a hemp line. Ring-shaped iron weights control the driver's impact on to the sea floor, and the sample obtained is retained within the tube by a valve, which closes, allowing mud or ooze to be brought safely to the surface (pl. 2). This device was similar to the Baillie sounding machine used on the cruise of HMS *Challenger* (1872–1876). Soundings taken in this way required the vessel to be stopped and turned to face the wind, to be kept as near stationary as possible. Inevitably, however, strains imparted by heavy swells in the Southern Ocean meant that some failures occurred.

The Kelvin sounding machine, employed for shallow water depths, and mounted on the after-deck of the *Aurora*, was similarly based on a drum whereon wire was paid out and depths measured on a graduated dial. In this case the wire was retrieved using hand power. The mechanism employed by this device meant that soundings could be taken while the ship was still steaming along.

Trawling was a much more complex and time-consuming operation than sounding and dredging, and was primarily carried out to recover biological materials. The *Aurora* carried a Monegasque trawl, named for the Prince of Monaco, Albert I, who had a keen interest in oceanography. Trawling with this apparatus required a wooden derrick and a steam windlass to drag a wide-mouthed net over the bottom, for periods of an hour or more. While the emphasis of this operation was clearly on biological investigations, comments from Mawson (1915, p.407), show that geological factors sometimes interfered with the biology. He wrote: "Unfortunately for biological considerations, our catches often partook too much of a geological character; stones great and small, several of which hauled on board actually weighed half a ton each, were most unwelcome items, for they tore the net and crushed the contents. It was thus ascertained that the oozy floor of the sea in those waters is abundantly sprinkled with rocks which arrived at their present resting place upon release from icebergs, embedded in which they had floated out from the land. Each stone

PLATE 1
The Lucas automatic sounding machine. (From J.K. Davis. Soundings. AAE Reports, Series A, vol. II, Plate VII.)

PLATE 2
The Lucas machine with Chief Officer Fletcher holding up the driver loaded with annular weights, ready to obtain a bottom sample and depth determination. (From J.K. Davis. Soundings. AAE Report Series A, vol. II, Plate VII.)

showed just how far it had been sunk in the mud, for the upper protruding part was blackened with a curious deposit of manganese oxide".

Curiously, there is little information on the fate of the rocks collected in this manner. No record of them appears in Mawson's catalogue of the rocks collected on the expedition (Mawson 1940a) nor are they dealt with in his account of the sedimentary rocks (Mawson 1940b). One exception, however, is the report of the dredging of several small specimens of lignite or brown coal at two sites off the west side of the Mertz Glacier Tongue. Speculatively, Mawson (1940b) considered that these might be from either brown coal beds in place on the sea floor, or else transported from the land with other debris from moraines. These lignites now appear to be lost.

In spite of the loss of this material, it is of historical interest to note here the circumstances of their dredging. This was on the last voyage – the homeward voyage – of the *Aurora*. Mawson (1915, p.405) wrote: "It was a miserable Christmas Day, and a little better on the 26th. That afternoon, however, it cleared sufficiently to reveal a hazy view of the coast. By 10pm the wall of the Mertz Glacier Tongue was visible on the port bow...Allowing a day for the weather to become clearer and more settled, we got out the trawl and made a successful dredging in three hundred fathoms close to the glacier tongue. In addition to the usual items, several fragments of fossilized wood and coaly matter were discovered in the oozy mud that came up in quantities with the catch".

The lack of records of the rest of the dredged rocks is surprising in that it should have been apparent, particularly to a geologist of Mawson's calibre, that valuable information might have been derived from this material in understanding the geology of both inland and coastal regions of East Antarctica. The value of clasts recovered recently from dredge hauls of glaciomarine sediments has been demonstrated in a number of contemporary studies, which have used petrographic and geochemical data (especially U–Pb zircon age studies) to identify the area and age of source sequences beneath inland ice cover. For example, clasts from the Wilkes Land margin, including some from regions covered by Mawson, such as that close to the Mertz Glacier, have provided key insights into the Precambrian basement of the East Antarctic Shield inland from this coast (see Domack 1982, and summaries in Goodge & Fanning 2010, Veevers & Saeed 2011).

The nature of the sea-floor deposits recovered from the driver tubes of the Lucas machine was described in detail in the report series by the palaeontologist Frederick Chapman (1922). In addition to brief descriptions of the bottom samples, including bathymetry, physical characteristics, organic content, and short descriptions of the foraminiferal genera encountered, Chapman provided some generalised comments about the distribution of sediment types. For example, during the second Antarctic cruise, roughly along the meridian of 146° E, he noted that the series of samples showed well a gradation of sediment type from calcareous *Globigerina* ooze in the northern sector, through diatomaceous and spicular oozes to terrigenous oozes off the Antarctic margin.

PALYNOLOGICAL ANALYSIS OF THE SEA-FLOOR SEDIMENTS

The samples examined in the 1982 study were from collections held by the Australian Museum in Sydney, although, as noted, the lignites mentioned by Mawson from the Mertz Glacier region could not be found. In that study, data from Mawson's dredge samples were supplemented by material from the tops of piston cores taken from Cruise 37 of the USNS *Eltanin* in 1968.

Within the sampled region, extending from the main base at Commonwealth Bay to the quarters of the Western Party on the western edge of the Shackleton Ice Shelf, concentrations of recycled palynomorphs were high at three localities – high enough to suggest that eroding sedimentary sequences were not far distant from the sites of deposition. These points of concentration were: the western side of the Shackleton Ice Shelf; an area on the western side of the Mertz Glacier tongue; and a region to the east of Cape Carr. Details of the assemblages, listing palynomorph taxa and their known stratigraphic ranges, were given in Truswell (1982) and are only briefly summarised here. More comprehensive lists of the taxa identified were given in Truswell (1983), together with illustrations. In the 30 years since the publication of the 1982 paper, considerable advances have been made in understanding the stratigraphic ranges of a number of palynomorph taxa, particularly in Australian sedimentary sequences. Where relevant, comments noting these refinements in age ranges have been incorporated below.

SHACKLETON ICE SHELF

The Shackleton Ice Shelf, named by Douglas Mawson, is one of the largest ice shelves on the East Antarctic margin, extending for some 385 km off the coast between longitudes 95°E and 105°E. It was encountered by the US Exploring Expedition under Charles Wilkes in 1840; after his long exploration from the east along the ice-bound coast, Wilkes retreated and turned north at what he termed "Termination Land". Figure 3 (redrawn from Mawson 1942) shows "Termination Tongue" as part of the ice shelf. It also shows the position of the small Helen Glacier in the west, and the larger Denman Glacier to the east – the latter proving a barrier that members of Mawson's Western Party under Frank Wild were unable to cross because of its intense crevassing. A more recent analysis of continental ice drainage into the Shackleton Glacier (Urbini *et al.* 2010) is discussed below.

In the 1982 study, samples dredged from the *Aurora* near the seaward end of the Shackleton Ice Shelf (Samples 141, 141A, 141B, 142) were the most productive of all, yielding palynomorph densities between 1500 and 2000 grains per gram of sediment. These recycled microfossils fall into three broad age groups: Permian, Late Jurassic to Early Cretaceous, and Late Cretaceous to Early Cenozoic. The species identified are listed in Truswell (1982, Tables 1–3). All show good to excellent preservation, indicating that levels of organic metamorphism are low to moderate, and suggesting that that they have been neither deeply buried nor affected by thermal metamorphism associated with igneous intrusion.

The Permian element observed here is of particular interest. It is among the best-preserved known to date from Antarctica. While Permian palynomorphs are common in

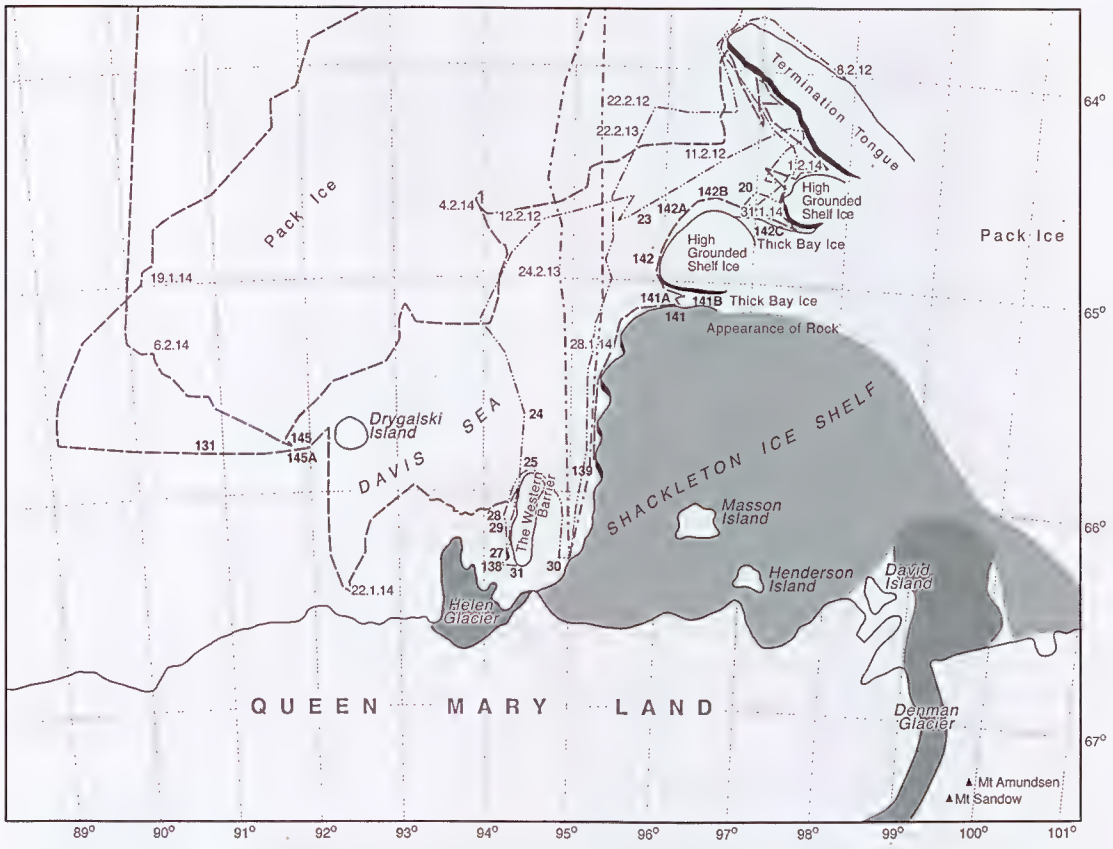

FIG. 3 — Map of Shackleton Ice Shelf area redrawn after Mawson (1914, 1942) and Truswell (1982). Geographic features labelled from Mawson, as are routes of SY Aurora; sample numbers after Chapman (1922).

all of the dredged samples, they are most abundant in the southern part of the area – in samples 25 and 39 they make up 33% and 55%, respectively, of total palynomorph counts. Within this non-marine assemblage, some taxa are held in common with those known from the Amery Group of the Prince Charles Mountains, exposed in the Lambert Graben, inland from Prydz Bay, far to the west of the Shackleton Ice Shelf. However, there is an element in the recycled assemblage that suggests erosion from beds that are older than any known from that sequence. The palynology and biostratigraphy of the Amery Group was reviewed by Playford (1990), who considered that assemblages described by a number of authors from the exposed formations of that Group (Radok Conglomerate, Bainmedart Coal Measures, Flagstone Bench Formation) were essentially of Late Permian age – equivalent to his *Praecolpatites* Zone of Antarctica or to Stage 5 of the Australian Permian. An extension of the Amery sequence into the Late Triassic – on the basis of palynology – was described by Foster *et al.* (1994).

Within the recycled assemblage offshore from the Shackleton Ice Shelf, several observed species are restricted to, or most common in, palynological assemblages referred to as Stage 2, or Stages 3–4, in Australia, or their equivalents in the *Parasaccites* and *Protohaploxypinus* Zones in Beacon Group sequences of the Transantarctic Mountains (see Playford 1990), which are probably of Early Permian and possibly Late Carboniferous age. Palynomorphs from that sequence, however, are darkened and corroded, having suffered severely from thermal metamorphism associated with intrusion of the Ferrar Dolerites. This contrasts with the excellent preservation of the recycled material. Sources for the Permian elements in the Shackleton Ice Shelf dredges are speculative, but some possibilities are canvassed below.

The most diverse element among the recycled palynomorphs in the area was assigned to the Late Jurassic to Early or Mid Cretaceous (Truswell 1982). A more precise breakdown of the possible age ranges of units within the eroding source beds that may have contributed these palynomorphs was based on known age ranges of selected species in Australian sedimentary basins, but some caution should be emphasised here in that ranges may not be precisely parallel in Antarctica. Both quantitative data – general abundance of major groups – and the ranges of selected individual species suggest that beds of Late Jurassic through to Albian ages may have been included within the source beds. Updating of the palynostratigraphy of Australian basins confirms these original age assignments. For instance, the appearance of the spore species *Coptospora paradoxa* (Cookson & Dettmann) defines the base of a nominate zone in Australia to which an Early to Lower Late Albian age range has been assigned (see Helby *et al.* 1987). The associated species *Trilobosporites trioreticulosus* Cookson & Dettmann, also present in the Shackleton Ice Shelf samples, similarly defines the base of that zone, confirmed by recent studies in Australia's Gippsland Basin (Wagstaff *et al.* 2012). Elsewhere in East Antarctica, sediments referred to the *C. paradoxa* Zone were reported from DSDP Site 741, in Prydz Bay (Truswell 1991). This putative Cretaceous sequence appears to have been primarily non-marine, although a single Cretaceous dinocyst hints at a minor marine component.

The third element in the area, of Late Cretaceous to Early Cenozoic age, includes a suite of well-preserved dinoflagellate cysts as well as a distinctive pollen assemblage. Dinocysts are most abundant in the dredge samples labelled 141

and 142. Some of these typify what has been referred to as the "Transantarctic Flora". This assemblage consists of a number of species that appear to have been endemic to high southern latitudes; several authors have reviewed this flora (see for example Wrenn & Hart 1988, Truswell 1999, Levy & Harwood 2000). Most recently, Bijl *et al.* (2011) investigated the spatio-temporal distribution of endemism in high-latitude dinocysts, and observed that a switch from cosmopolitan-dominated to endemic-dominated assemblages occurred around the Early–Middle Eocene boundary, perhaps in response to nutrient availability linked to ocean circulation changes. The prevalence in the Shackleton Ice Shelf assemblages of species such as *Arachnodinium antarcticum* Wilson & Clowes and a distinctive suite of *Deflandrea* species identifies these assemblages as belonging to this endemic flora. Further, some species, including *A. antarcticum*, are known to have major abundances in the Middle Eocene; the species is the nominate taxon for a dinocyst range zone of this age in the Gippsland Basin of southeastern Australia (Partridge *in* McGowran *et al.* 2000). Tentatively, these age distributions suggest that at least part of the eroding marine sequence contributing palynomorphs to the Shackleton Ice Shelf is of Middle Eocene age.

Pollen assemblages from these dredge samples contain taxa characteristic of Late Cretaceous to Eocene sequences in Australia, and from Eocene sediments drilled in Prydz Bay, Antarctica (Truswell & Macphail 2009). Assemblages typically contain a diversity of pollen related to that of modern *Nothofagus*, a limited suite of proteaceous forms, and species assigned to the form genus *Gambierina*, of unknown affinity.

MERTZ GLACIER REGION

In this area the Australasian Antarctic Expedition made its first landfall in January 1912, west of the Mertz Glacier Tongue. The first dredge sample, labelled A, was taken at 65°52'S, 143°39'E, and was retrieved from the edge of the continental shelf in the area. Subsequently, a number of samples were dredged close to the western edge of the Mertz Glacier. Productive samples in the area yielded, on maceration, spores and pollen predominantly of Early Cretaceous age. Included among the stratigraphically useful taxa identified was *Pilosisporites notensis* Cookson & Dettmann which is the nominate form for a palynozone of Aptian age in southern Australian basins (see for example Morgan *et al.* 1995), although the species ranges from the Late Neocomian into the basal Albian in the Gippsland Basin (Wagstaff *et al.* 2012). Forms more characteristic of the Albian in southern Australia were not observed here. The Early Cretaceous palynomorph suites obtained from the *Aurora* dredges are very similar in composition to assemblages recovered from an *in situ* brecciated siltstone retrieved by piston coring in the George V Basin, west of the Ninnis Glacier during Operation Deep Freeze in 1979 (Domack *et al.* 1980), and assigned a probable Aptian age on the basis of comparison with then known ranges in Australian sedimentary basins.

Present in lower frequencies were Late Cretaceous to Early Cenozoic taxa. A single grain of Permian age was recorded.

CAPE CARR AREA

A high concentration of recycled palynomorphs was recovered from an area lying off the edge of the continental shelf, slightly to the east of Cape Carr, an ice-covered cape named by Charles Wilkes of the US Exploring Expedition for Lieutenant Overton Carr of the *Vincennes* (Wilkes 1844). Mawson (1942), reporting in the narrative of the voyage (23 January 1912), noted that the ship's log stated that a sharp lookout was being kept for the land reported in 1840, but none was seen, and the *Aurora* had sailed over the site of Wilkes' Cape Carr (now designated as 66°7'S; 130°43'E).

The recycled material in the dredge samples taken off the edge of the shelf contains spores and pollen of Early to mid Cretaceous (? Albian to Cenomanian), and Late Cretaceous to Early Cenozoic ages; no Permian forms were recorded (Truswell 1982). Perhaps curiously, dredge samples on the shelf proper are nearly barren of recycled material, leading to the tentative suggestion that the recycled material may be eroding from strata cropping out on the steep slopes of the shelf break. While no new data have become available on the bathymetry or geology of this area since the 1982 study, the suggested presence there of sequences of Albian age is in line with ages suggested for the Shackleton Ice Shelf, and, more recently, for sequences offshore from Prydz Bay (Truswell 1991).

RELATIONSHIP TO BATHYMETRY, SUB-ICE TOPOGRAPHY AND GEOLOGY

Since the publication of the initial report on the distribution of the recycled palynomorphs in the dredge samples from the *Aurora* (Truswell 1982), there has been a number of advances in understanding the bathymetry of the continental shelf in parts of East Antarctica, and of the position of putative sedimentary basins on the continent that impact on the coastal margin. In some cases the palynomorph distributions appear to be clarified by the local bathymetric and geological setting; in others they raise questions that require further investigation. The two areas where data from these different sources intersect are in the vicinity of the Shackleton Ice Shelf, and of the Mertz Glacier off George V Land. No new data are available from the Cape Carr region.

SHACKLETON ICE SHELF

The distribution of palynomorphs in this area is outlined above. The relationship of these to the continental shelf bathymetry remains largely unknown, as the inaccessibility of the area has precluded major surveys. The bathymetry as shown in the 2008 Gebco map shows the tracks of ships collecting echo sounding data, and highlights the general lack of information on the continental shelf (fig. 4). However, a recent compilation of radio-echo sounding data from the Shackleton Ice Shelf does shed some light on the outlet glaciers flowing into the ice shelf, and on grounding lines within the shelf, all of which may be relevant to palynomorph distribution (Urbini *et al.* 2010). The small Helen Glacier on the western margin of the ice shelf appears to drain a continental area wherein no sequences younger than Cambrian are known. Among a number of glaciers draining into the eastern part of the ice shelf the Denman Glacier is the fastest and

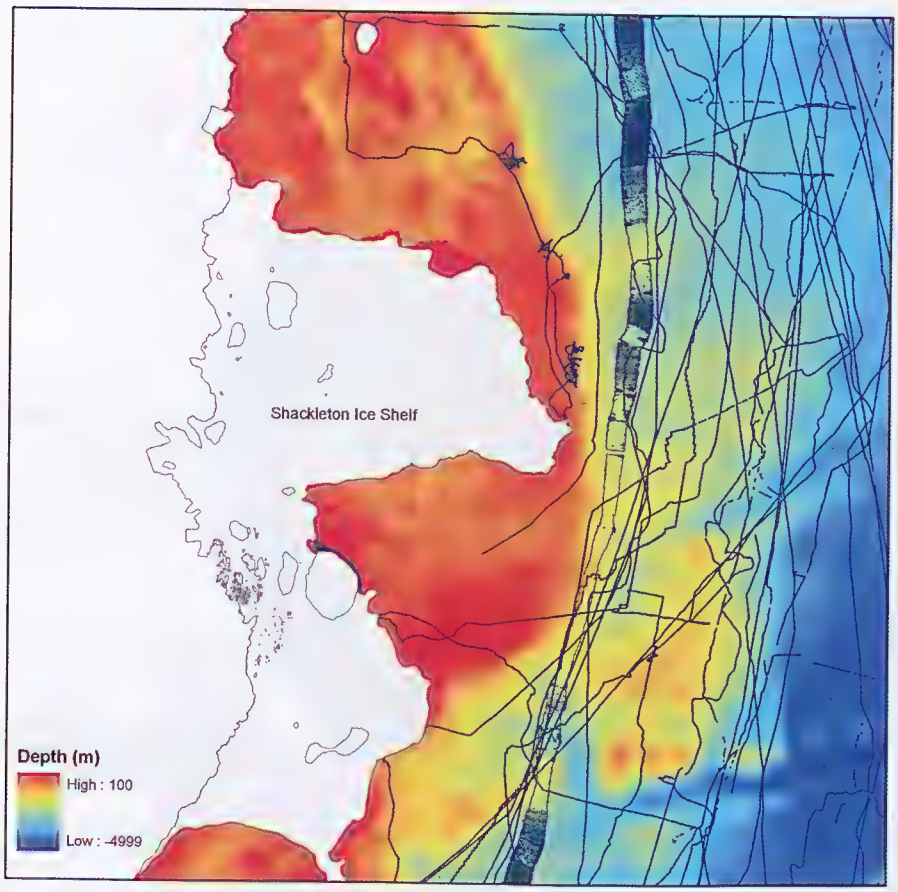

FIG. 4 — Shackleton Ice Shelf and surrounding continental shelf, with ship tracks showing all available single beam and multibeam echo-sounding data available for the area. The one multibeam survey line is the N–S trending line with the squiggles inside it just off the shelf break. This survey was conducted by the R/V Roger Revelle in 2007 (survey CLIVARI18S). (From GEBCO_08 grid, version 20100927. See http:www.gebco.net)

thickest (Urbini *et al.* 2010). While heavy crevassing has made definition of its valley contours difficult, it appears that the Denman Valley, bedrock to the Denman Glacier, may be up to 9 km wide and up to 2 km deep at the grounding line.

A clearer understanding of the sub-ice topography of inland Antarctica has been achieved in recent years through a combination of direct studies of ice thickness and modelling (Lythe *et al.* 2001, Roberts *et al.* 2011). Of possible relevance to sediment deposition in the Shackleton Glacier region is the definition of the Aurora Subglacial Basin. Roberts *et al.* (2011) presented a new reconstruction of the thickness of the ice sheet over parts of East Antarctica, using ice thickness measurements in combination with digital elevation modelling to derive the elevation of the base of the ice sheet. In so doing they defined the Aurora Subglacial Basin (fig. 5) as a large area where the base of the ice lies below present sea level, with deep submarine connections from the deep interior to the coastal zone. The Denman Glacier and the Totten Glacier have been identified as likely drainage outlets. Given this scenario, it is possible that the source of Permian material deposited near the Shackleton Ice Shelf may originate within the Aurora Subglacial Basin, but this remains a tentative suggestion.

Further, reconstructions between Antarctica and Australia, which are based on Precambrian basement provinces, show that part of the Shackleton Ice Shelf region abutted the southern part of the Perth Basin of southwestern Australia (see for example Fitzsimons 2003). There, the Sue Group represents a thick Permian section, where the Sue Coal Measures are overlain by Late Permian to Early Triassic Sandstones. It has been suggested that the Darling Fault of the Perth Basin may correlate with the Denman and Scott glaciers (see Fitzsimons 2003, Fig. 8). Given the possibilities presented by this reconstruction, the presence of eroding Permian sequences in this region of coastal East Antarctica would not be unexpected.

GEORGE V BASIN–MERTZ GLACIER REGION

The bathymetry of the offshore area where the *Aurora* dredge samples were collected is now better understood than it was in Truswell's 1982 study. There is now a higher density of digital bathymetric data available in this area than for other parts of East Antarctica. Beaman & Harris (2003) used echo-sounder data to establish the presence of a linear, inner shelf trough that lies parallel to the coast; they identified drifts of sediment lying to the west of the Mertz Glacier. The definition of these inner shelf basins was further improved by Beaman *et al.* (2010) using a combination of single and multibeam surveys, coastline data, and land and ice-sheet data to present a more refined bathymetric grid. The inner shelf depressions have been variously referred to as the George V

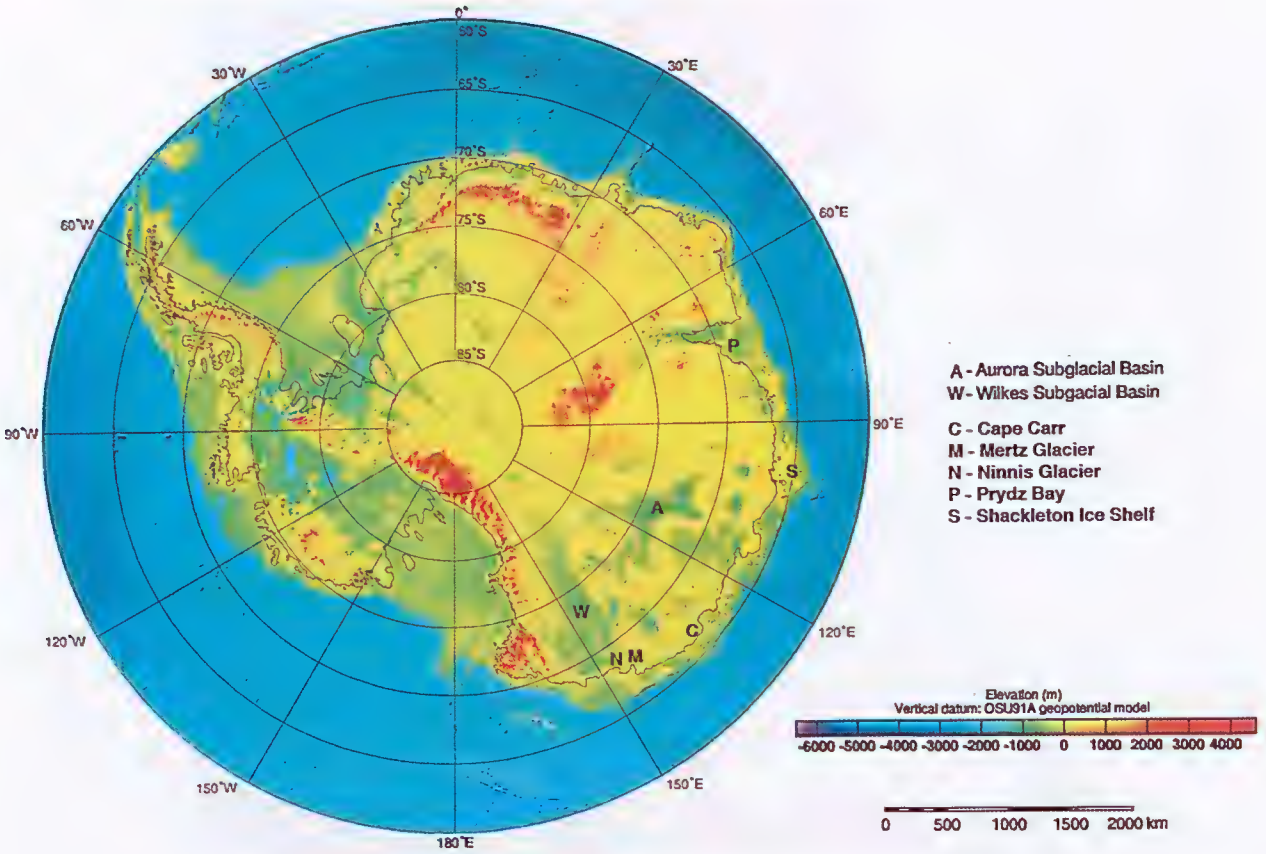

FIG. 5 — Sub-ice sedimentary basins, adapted from Lythe et al. 2001, plate 1. Major sites discussed in the text are also shown.

Basin, the Adélie Depression, or the Mertz-Ninnis Trough (figs 6, 7). This trough appears to extend to the east of the Mertz Glacier, but its topography is less well defined there due to scarcer data. Inner shelf troughs such as these are a feature of the East Antarctic margin, and may originate in Cenozoic fault traces that have been scoured and deepened by glacial action (Vanney & Johnson 1979).

The dredge samples collected from the *Aurora* that have been plotted on the recent bathymetric maps show that they were collected in part on the seaward edge of the Mertz-Ninnis Trough. These are the samples that yielded predominantly non-marine Early Cretaceous assemblages, and marine Late Cretaceous to early Cenozoic taxa (see above). An Early Cretaceous (Aptian) age was recorded too from the depression to the east of the Mertz Glacier (Domack *et al.* 1980). Further dredging, carried out during 2001 by the NB *Palmer* recovered sedimentary clasts from the seaward flank of the Mertz-Ninnis Trough. These yielded palynomorphs of Paleogene and Early Cretaceous age (Schrum *et al.* 2004); combined seismic data suggest that these represent seafloor outcrop or shallow subcrop sequences.

The available information suggests that the George V Basin (or Mertz-Ninnis Trough) is a deep depression similar to others that lie on the continental shelf parallel to the coast of East Antarctica between 90° and 150° E (Domack *et al.* 1980, Domack 1985). The established presence of Cretaceous and Cenozoic strata within this basin invites comparison both with basins on the southern margin of Australia, and with intracratonic basins on Antarctica, inland from this coastal region. The suggestions made by Domack (1985) and Truswell (1982, 1983) that palynomorph-rich sequences offshore from the Wilkes Land coast of Antarctica have their equivalents in sedimentary basins of the Great Australian Bight are confirmed and elaborated by recent seismic reflection data and sedimentology of the Antarctic margin (Close *et al.* 2007).

Seismic sequences in an area offshore from Wilkes Land and Terre Adélie, immediately to the west of the George V Basin, show the presence there of two major sedimentary basins, containing more than 9 km of sediments. Thick rift and pre-rift sequences are interpreted to be of Late Jurassic to mid-Cretaceous age on the basis of seismic correlation with the Australian margin. Reviews of the nature of the Australian margin (see for example Brown *et al.* 2003) show that rift stage sediments of Jurassic to mid-Cretaceous age extend through a number of sedimentary basins and sub-basins, including, from west to east, the Bremer Basin, Great Australian Bight Basin, Duntroon Basin, Otway and Sorell basins. On the Antarctic margin, sediments of this age have only been directly sampled in the George V Basin (Domack *et al.* 1980), but may be represented by the assemblages of recycled palynomorphs from the Shackleton Ice Shelf, Cape Carr and the Mertz Trough. These assemblages are essentially non-marine in character.

Post-rift sediments, which are concentrated in a major depocentre off west Wilkes Land, contain sequences of Late Cretaceous to Paleogene and younger sediments.

FIG. 6 — George V Basin, offshore from George V Land, showing shelf bathymetry and location of Aurora dredge samples as documented by Chapman (1922). Dark shading on the shelf represents a ridge facies identified by Beaman & Harris (2003). Sample A at the shelf edge, is the first dredge taken on the Expedition. (Modified from Beaman & Harris (2003, fig. 2).)

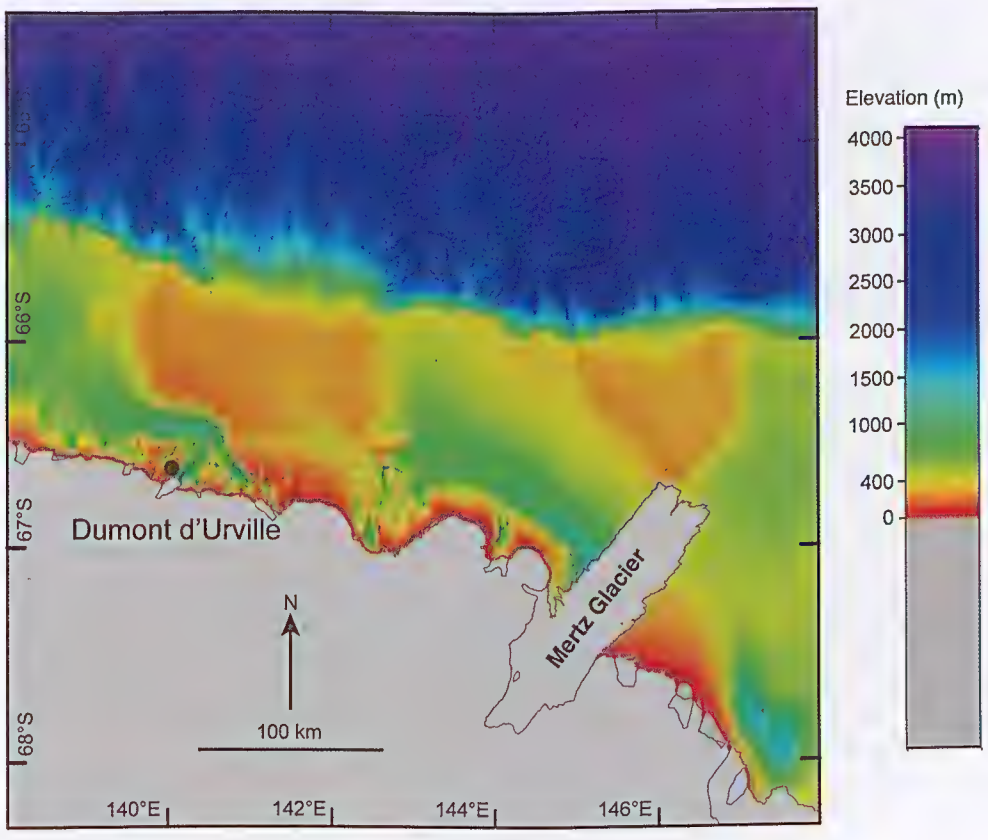

FIG. 7 — Bathymetric map of George V continental margin, based on single beam and multibeam echosounding data, showing the deep trough lying parallel to the coast and adjacent to the Mertz Glacier (From Beaman et al. 2010, fig.1a.)

While the Cretaceous and Paleogene sediments inferred from the recycled palynomorphs off the Mertz Glacier Trough lie slightly to the east of the seismic study area, they are likely to represent the same post-rift sequences. The relationship of the Antarctic basins to those of the Australian margins, as interpreted from the seismic data, and using oceanic fracture zones and seismic anomalies (see Close *et al.* 2007, Fig. 1) confirms the suggestion that the George V Basin sequences should be conjugate with those of the Otway Basin of southern Australia, although they would lie slightly to the west of that basin, in the area of the Beachport Plateau (Beachport sub-basin).

The possibility that major sedimentary basins in the hinterland of East Antarctica may intersect the coast in the region of the Mertz and Ninnis glaciers was explored in the 1970s and 1980s by Drewry (1976) and Steed & Drewry (1982), and noted in Truswell (1982). Reconnaissance airborne radar data were used then to define the Wilkes Subglacial Basin as a major, 1400 km-long subglacial depression, with its maximum width of 600 km occurring at the George V Coast. These early studies gave rise to speculation that the Wilkes Subglacial Basin contained Beacon Supergroup sediments overlain by significant thicknesses of Mesozoic and Cenozoic sediments.

New aeromagnetic and airborne radar data (Ferraccioli *et al.* 2009) have shown this subglacial basin to be extremely complex in terms of sub-ice topography and inferred geology. That study, based essentially on detail of the central part of the basin, reveals a number of sub-basins, which contain, *inter alia,* Jurassic dolerites of the Ferrar Group, but indicates that there is little likelihood of any significant thickness of post-Jurassic sediments. Such younger sedimentary infill, if it exists, is likely to be localised and thinner than originally suggested by Drewry (1976).

However, it should be noted that the data remain sparse for localised basins in the western margin of the larger subglacial basin, and the nature of aeromagnetic anomalies there (including in the coastal region) could be explained by the presence of post-Jurassic sedimentary infill. The larger, "continent-scale" evaluations for the nature and thickness of the basin infill thus do not appear to rule out more localised sedimentary basins impacting on the George V coast.

SEDIMENTARY PROCESSES AND DISTRIBUTION OF RECYCLED PALYNOMORPHS

The value of reworked palynomorphs as a basis for determining the provenance of sedimentary sequences was discussed by Batten (1991), who pointed out that these microfossils have largely been under-utilised as a tool in stratigraphy. In his review, Batten drew attention to the application of the recycled palynomorphs in Antarctic shelf sediments, noting that these represent an exception to this generalisation.

Palynomorphs recovered from superficial sea-floor sediments on the Antarctic margin must originate from the erosion of sedimentary sequences cropping out either on the adjacent continent, or on the sea floor itself. Processes relevant to their distribution will clearly vary depending on local conditions, such as sea-floor topography and the proximity, or otherwise, of ice shelves. Bottom currents are likely to be a major factor controlling the microfossil distribution. A range of factors will thus influence the observed distributions, and processes will differ between individual sites.

However, two studies suggest that – at least in some cases – the assemblages of palynomorphs are not redistributed very far from the site of their initial deposition on the sea floor, and hence from their source areas. In the Ross Sea, for example, a quantitative study of palynomorph distribution (Truswell & Drewry 1984) suggested that palynomorphs, which have their source in sequences below the Ross Ice Shelf, have initially melted out of sediment beneath the shelf, probably close to the grounding line. In this region, concentrations appear to be closely related to particular ice streams. Past advances of the shelf have "bulldozed" the pollen-bearing sediment seaward. Thereafter, however, bottom currents appear to have had only a minor role in their redistribution, as microfossils from East and West Antarctica remain in clearly separate areas on the Ross Sea floor (see Truswell & Drewry 1984, Fig. 1).

A second area that also suggests minimal distribution of recycled palynomorphs by bottom currents occurs on the Mac.Robertson Shelf, to the west of Prydz Bay. There, palynomorphs ranging in age from Early Jurassic to Early Cretaceous were recovered from shallow drilling that penetrated Quaternary sediments in the arcuate trough that is the Neilsen Basin. The palynomorphs are clearly recycled into these sediments, yet the composition of assemblages recovered from individual samples shows these to lie in stratigraphic sequence, indicating that no mixing has occurred between closely spaced samples. The inference is that the sediments were deposited very close to the eroding source rocks (Truswell *et al.* 1999). In all probability, these source rocks underlie the Quaternary cover in the immediate vicinity.

SUMMARY AND CONCLUSIONS

Sedimentary material recovered by dredging of the sea floor during the Antarctic cruises of the Australasian Antarctic Expedition of 1911–1914 continues to provide information that sheds light on the geology of the East Antarctic margin. During that expedition, dredge samples were recovered in a sweep of coastline extending from close to the main base at Commonwealth Bay, to the western edge of the Shackleton Ice Shelf. Bottom sediments recovered during the dredging were shown to yield palynomorphs that have been recycled from eroding sedimentary sequences. Some 53 dredge samples were examined for their palynomorph content in an earlier study (Truswell 1982). That study, published in the centenary of Mawson's birth, showed high concentrations in three regions of the continental shelf, namely, offshore from the Shackleton Ice Shelf, from Cape Carr, and from close to the Mertz Glacier.

In the centenary year of the departure of the expedition, the findings of the earlier study have been re-evaluated in the light of new information that has accumulated in relation to the bathymetry of the sampled areas of the continental shelf, the sub-ice topography of ice shelves and the Antarctic interior, and of the sedimentary processes controlling the movement of palynomorphs in sea-floor sediments. In brief, the main results of the present survey are as follows:

1. The most productive samples, yielding densities of 1500–2000 grains per gram of sediment, occur near the seaward end of the Shackleton Ice Shelf. The age groups represented include Early and Late Permian, Late Jurassic–

Early Cretaceous (including Albian) and Late Cretaceous–Early Cenozoic palynomorphs, all showing excellent preservation. The Permian element in particular is better preserved than any previously described from Antarctica, suggesting neither deep burial nor thermal metamorphism. While the source of such material remains speculative, recent reconstructions suggest that Australia and Antarctica may have been conjoined in the region of the southern Perth Basin, where thick Permian and Triassic sequences occur. Hence sediments of this age might not be unexpected in this sector of Antarctica. Further, the Darling Fault of the Perth Basin may correlate with the Denman and Scott glaciers. New data on sub-ice topography shows the Denman Glacier to be one of the major drainage outlets flowing into the Shackleton Ice Shelf, and suggest that it may have connections with the deep Aurora Subglacial Basin of the interior. Hence, there is a possibility that the source of the Permian material may lie within this interior basin.

2. Samples collected on the continental shelf to the west of the Mertz Glacier are now shown to lie mostly on the edge of the steep trough that is the George V Basin. New echo-sounding data has clarified the bathymetry of this feature, which is typical of similar features in other areas of the Antarctic continental shelf. Recycled palynomorphs present in these samples suggest the presence of eroding sequences of Early Cretaceous (as young as Aptian) age, in addition to Late Cretaceous through Cenozoic sequences. The previous suggestion that these sequences may correlate with those of the Otway Basin on the Australian margin is corroborated by recent seismic reflection data showing the presence of thick rift and pre-rift sequences offshore from the Adélie and Wilkes coasts.

Previous suggestions that Mesozoic and Cenozoic sediments on this part of the Antarctic margin may be related to sediment fill in the extensive Wilkes Basin of the inland need to be reassessed in the light of better understanding of the nature of that basin, based on fresh aeromagnetic and airborne radar surveys. These suggest that there is little likelihood of any significant thickness of post-Jurassic sediments in that basin, although the possibility that small Mesozoic basins might lie in the western part of the major basin cannot be ruled out.

3. While it is difficult to generalise about the factors controlling the erosion of palynomorphs from sedimentary sequences that either crop out on the sea floor or lie beneath glacial cover, two studies – one in the Ross Sea, another on the Mac.Robertson Shelf – indicate that there has been little movement of the microfossils by current action after their deposition on the sea floor. These studies, although areally restricted, increase confidence in the value of this recycled material as a tool in identifying the proximity of source rocks.

ACKNOWLEDGEMENTS

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REFERENCES

Batten, D.J. 1991: Reworking of plant microfossils and sedimentary provenance. *In* Morton, A.C., Todd, S.P. & Haughton, P.D.W. (eds): Developments in sedimentary provenance studies. *Geological Society Special Publication* **57**: 79–90.

Bayley, P.G.W. & Stillwell, F.L. 1923: The Adélie Land meteorite. Australasian Antarctic expedition 1911– 1914. *Scientific Reports Series A,* **4**: 1–15.

Beaman, R.J. & Harris, P.T. 2003: Seafloor morphology and acoustic facies of the George V Land Shelf. *Deep Sea Research* II **50**: 1343–1355.

Beaman, R.J., O'Brien, P.E., Post, A.L. & De Santis, L. 2010: A new high-resolution model for the Terre Adélie and George V continental margin, East Antarctica. *Antarctic Science* **23**: 95–103.

Bijl, P.K., Pross, J., Warnaar, J., Stickley, C.E., Huber, M., Guerstein, R., Houben, A.J.P., Sluis, A., Visscher, H. & Brinkhuis, H. 2011: Environmental forcings of Paleogene Southern Ocean dinoflagellate biogeography. *Paleoceanography* **26**, PA1202, doi:10.1029/2009PA001905.

Brown, B.J., Muller, R.D., Gaina, C., Struckmeyer, H.I.M., Stagg, H.M.J. & Symonds, P.A. 2003: Formation and evolution of Australian passive margins: implications for locating the boundary between continental and oceanic crust. *In* Hillis, R.R. & Muller, R.D. (eds): *Evolution and Dynamics of the Australian Plate*. Geological Society of America Special Paper **372**: 223–243.

Browne, W.R. 1923: The dolerites of King George Land and Adélie Land. Australasian Antarctic Expedition 1911–1914. *Scientific Reports, Series A,* **3**: 246–260.

Chapman, F. 1922: Sea-floor deposits from soundings. Australasian Antarctic Expedition 1911–14. *Scientific Reports, Series A,* **2**: 1–60.

Close, D.J., Stagg, H.M.J. & O'Brien, P.E. 2007: Seismic stratigraphy and sediment distribution on the Wilkes Land and Terre Adélie margins, East Antarctica. *Marine Geology* **239**: 33–57.

Coulson, A.L. 1925: Magnetite garnet rocks from the moraines at Cape Denison, Adélie Land. Australasian Antarctic Expedition 1911–1914. *Scientific Reports, Series A,* **3**: 281–307.

Davis, J.K. 1939: Soundings. Australasian Antarctic Expedition 1911–1914. *Reports, Series A,* **2**, Part 3: 87–102.

Domack, E.W. 1982: Sedimentology of glacial and glacial marine deposits on the George V– Adélie continental shelf, East Antarctica. *Boreas* **11**: 79–97.

Domack, E.W. 1985: Glacial erosion on the George V/Adélie continental margin, East Antarctica. *Antarctic Journal of the United States* **19**: 76–78.

Domack, E.W., Fairchild, W.W. & Anderson, J.B. 1980: Lower Cretaceous sediment from the East Antarctic continental shelf. *Nature* **287**: 625–626.

Drewry, D.J. 1976: Sedimentary basins of the East Antarctic craton from geophysical evidence. *Tectonophysics* **36**: 301–314.

Ferraccioli, F., Armadillo, E., Jordan, T., Bozzo, E. & Corr, H. 2009: Aeromagnetic exploration over the East Antarctic ice sheet: A new view of the Wilkes Subglacial Basin. *Tectonophysics* **478**: 62–77.

Fitzsimons, I.C.W. 2003: Proterozoic basement provinces of southern and southwestern Australia and their correlation with Antarctica. *In* Yoshida, M., Windley, B.F. & Dasgupta, S. (eds): Proterozoic East Gondwana; supercontinent assembly and breakup. *Geological Society of London Special Publication* **206**: 93–130.

Foster, C.B., Balme, B.E. & Helby, R. 1994: First record of Tethyan palynomorphs from the Late Triassic of East Antarctica. *AGSO Journal of Geology & Geophysics* **15**: 239–246.

General Bathymetric Map of the Oceans 2008: **GEBCO _ 08 Grid.** version 20100927. http://www.gebco.net.

Glastonbury, J.O.G. 1940: Certain epidotic rocks from the moraines at Commonwealth Bay. Australasian Antarctic Expedition 1911–1914. *Scientific Reports Series A,* **4**: 183–196.

Goodge, J.W. & Fanning, C.M. 2010: Composition and age of the East Antarctic Shield in eastern Wilkes Land determined by proxy from Oligocene – Pleistocene glaciomarine sediment and Beacon Supergroup sandstones, Antarctica. *Geological Society of America Bulletin* **122**: 1135–1159.

Helby, R., Morgan, R. & Partridge, A.D. 1987: A palynological zonation of the Australian Mesozoic. *Association of Australasian Palaeontologists, Memoir* **4**: 1–94.

Hince, B. (ed.) 2012: *Still no Mawson: Frank Stillwell's Antarctic diaries 1911–1913.* Australian Academy of Science, Canberra.

Levy, R.H. & Harwood, D.M. 2000: Tertiary marine palynomorphs from the Mcmurdo Sound erratics, Antarctica. *In* Stilwell, J.D. & Feldmann, R.M. (eds): *Paleobiology and Paleoenvironments of Eocene Rocks, McMurdo Sound, Antarctica.* American Geophysical Union, Antarctic Research Series, **76**: 183–242.

Lythe, M.B., Vaughan, D.G. & the BEDMAP Consortium 2001: BEDMAP: a new ice thickness and subglacial topographic model of Antarctica. *Journal of Geophysical Research* **106**: 11335–11351.

McGowran, B., Archer, M., Bock, P., Darragh, T.A., Godthelp, H., Hageman, S., Hand, S.J., Hill, R., Li, Q., Maxwell, P.A., McNamara, K.J., Macphail, M., Mildenhall, D., Partridge, A.D., Richardson, J., Shafik, S., Truswell, E.M. & Warne, M. 2000: Australasian palaeobiogeography: the Palaeogene and Neogene record. *Memoir of the Association of Australasian Palaeontologists* **23**: 405–470.

Mawson, D. 1914: Australasian Antarctic Expedition, 1911–1914. *The Geographical Journal,* **44** (3): 258–284.

Mawson, D. 1915: *The Home of the Blizzard* (first published by Heinemann, London). Edition published 2010, Wakefield Press, Adelaide: 536 pp

Mawson, D. 1940a: Sedimentary Rocks. Australasian Antarctic Expedition 1911–1914. *Scientific Reports,* Series *A,* **4**: 347–367.

Mawson, D. 1940b: Catalogue of Rocks and Minerals collected in Antarctic Lands. Australasian Antarctic Expedition 1911–1914. *Scientific Reports,* Series *A,* **4**: 405–432.

Mawson, D. 1942: Narrative and Cartography. Australasian Antarctic Expedition 1911–1914. *Scientific Reports* Series *A,* **1**: 1–492.

Morgan, R., Rowett, A.I. & White, M.R. 1995: Biostratigraphy. Great Australian Bight. *Petroleum Geology of South Australia* **5**. South Australian Government: 1–46.

Playford, G. 1990: Proterozoic and and Paleozoic palynology of Antarctica: a review. *In* Taylor, T.N. & Taylor, E.L. (eds): *Antarctic Paleobiology. Its Role in the Reconstruction of Gondwana.* Springer Verlag, New York: 51–70.

Roberts, J.L., Warner, R.C., Young, D., Wright, A., van Ommen, T.D., Blankenship, D.D., Seigert, M., Young, N.W., Tabacco, I.E., Forieri, A., Passerini, A., Zirizotti, A. & Frezzotti, A. 2011: Refined broad-scale morphology of Aurora Subglacial Basin, East Antarctica derived by an ice-dynamics-based interpolation scheme. *The Cryosphere Discussions* **5**: 655–684.

Schrum, H., Domack, E., Desantis, L., Leventer, A., McMullen, K., Escutia, C. 2004: A glimpse at Late Mesozoic to Early Tertiary offshore stratigraphy from Wilkes Land, East Antarctica: Results of strategic dredging of the Mertz-Ninnis Trough. *American Geophysical Union, Fall Meeting, Abstract* PP51E–1359.

Steed, R.H.N. & Drewry, D.J. 1982: Radio echo-sounding investigations of Wilkes Land, Antarctica. *In* Craddock, C. (ed.): *Proceedings of the 3rd International Symposium on Antarctic Geology and Geophysics.* University of Wisconsin Press: 969–975.

Stillwell, F.L. 1918: The metamorphic rocks of Adélie Land. Australasian Antarctic Expedition 1911–1914. *Scientific Reports, Series A,* **3**: 1–266.

Stillwell, F.L. 1923: Amphibolites and related rocks from the moraines, Cape Denison. Australasian Antarctic Expedition 1911–1914. *Scientific Reports, Series A,* **3**: 261–280.

Summers, H.S. & Edwards, A.B. 1940: Granites of King George Land and Adélie Land. Australasian Antarctic Expedition 1911–1914. *Scientific Reports Series A,* **4**: 87–113.

Truswell, E.M. 1982: Palynology of sea-floor samples collected by the 1911–1914 Australasian Antarctic Expedition: implications for the geology of coastal East Antarctica. *Journal of the Geological Society of Australia* **29**: 343–356.

Truswell, E.M. 1983: Recycled Cretaceous and Tertiary pollen and spores in Antarctic marine sediments: a catalogue. *Palaeontographica* Abt.B **186**: 121–174.

Truswell, E.M. 1991: Data report: Palynology of sediments from Leg 119 drillsites in Prydz Bay, East Antarctica. *In* Barron, J., Larsen, B. *et al.*: *Proceedings of the Ocean Drilling Program, Scientific Results,* **119**: 941–945.

Truswell, E.M. 1999: Palynomorph assemblages from marine Eocene sediments on the west Tasmanian continental margin and the South Tasman Rise. *Australian Journal of Earth Sciences* **44**: 633–654.

Truswell, E.M. & Drewry, D.J. 1984: Distribution and provenance of recycled palynomorphs in surficial sediments of the Ross Sea, Antarctica. *Marine Geology* **59**: 187–214.

Truswell, E.M., Dettmann, M.E. & O'Brien, P.E. 1999: Mesozoic palynofloras from the Mac.Robertson Shelf, East Antarctica: geological and phytogeographic implications. *Antarctic Science* **11**: 239–255.

Truswell, E.M. & Macphail, M.K. 2009: Polar forests on the edge of extinction: what does the spore and pollen evidence from East Antarctica say? *Australian Systematic Botany* **22**: 57–106.

Urbini, S., Cafarella, L., Zirizzotti, A., Tabacco, I.E., Bottari, C., Baskaradas, J.A. & Young, N. 2010: Radio echo sounding data analysis of the Shackleton Ice Shelf. *Annals of Geophysics* **53**: 79–87.

Vanney, J.R. & Johnson, G.L. 1979: Wilkes Land continental margin physiography, East Antarctica. *Polar Forschung* **49**: 20–29.

Veevers, J.J. & Saeed, A. 2011: Age and composition of Antarctic bedrock reflected by detrital zircons, erratics, and recycled microfossils in the Prydz Bay–Wilkes Land–Ross Sea–Marie Byrd Land sector (70°– 240° E). *Gondwana Research* **20**: 710–738.

Wagstaff, B.E., Gallagher, S.J. & Trainor, J.K. 2012: A new subdivision of the Albian spore-pollen zonation of Australia. *Review of Palynology and Palaeobotany* **171**: 57–72.

Wilkes, C. 1844: Narrative of the United States Exploring Expedition during the years 1838, 1839, 1840, 1841, 1842. Vols 1–5. C. Sherman, Philadephia.

Wrenn, J.H. & Hart, G.F. 1988: Palaeogene dinoflagellate cyst biostratigraphy of Seymour Island, Antarctica. *Geological Society of America Memoir* **169**: 321–447.

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ANTARCTIC VIGNETTES VI: LESLIE RUSSELL BLAKE – MAWSON'S FORGOTTEN GEOLOGIST

by Herbert J.G. Dartnall

with four plates

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Leslie Russell Blake was a young Australian surveyor and geologist of great talent who made an outstanding contribution to our knowledge of Macquarie Island whilst a member of Douglas Mawson's Australasian Antarctic Expedition (AAE) during 1911–1914. He was a member of the five-man team that spent nearly two years on Macquarie Island establishing their base at the northern end of the island. Blake spent much of his time away from the base surveying and making geological observations. His topographical map of the island was the standard until modern techniques such as aerial photography, satellite imagery, airborne synthetic aperture radar and GPS technology enabled the island to be mapped in detail. During the First World War Blake served with the Australian Imperial Forces and was awarded a Military Cross for a survey of the front line before the attack at Pozières. His death just days before the end of the First World War meant that he never finished writing up his scientific notes. It says much for the quality of his field reports that Douglas Mawson was eventually able to publish the work. Sadly, the fact that it was not published until 1943, and then only under Mawson's name, meant that Leslie Russell Blake has been largely forgotten.

Key Words: Leslie Russell Blake, geologist, Macquarie Island, Mawson, surveying, Australasian Antarctic Expedition.

INTRODUCTION

This paper, the sixth in the Antarctic Vignette series (Dartnall, 2008a, b, 2009a, b, 2011), arises from a presentation at a symposium celebrating the centenary of the departure of the Australasian Antarctic Expedition (AAE) in 1911.

Douglas Mawson recruited four geologists for the AAE — one for each of the bases he hoped to establish. In the event only two of the three Continental bases were established: Charles Archibald Hoadley and Andrew Dougal Watson doubled up at the Western Base, while Francis Leslie Stillwell was stationed at the Main Base at Cape Denison. While these three men are comparatively well known, and all have entries in the *Australian Dictionary of Biography* (Lack 1983, Wilcock 1990, Price 2005), Leslie Russell Blake, the man destined for Macquarie Island, has no such entry and is one of the forgotten men of the expedition.

EARLY LIFE

Leslie Russell Blake was born on 28 October 1890 in Hawthorn, Victoria, the sixth and youngest child of Thomas Henry Blake and Maria Louisa Blake née Purdey. Leslie's father, who was born at Stowmarket in Suffolk, England, in 1851, emigrated to Australia in early 1873. A photographer, he married Leslie's mother at South Yarra in 1878. She was born in1857 at Kandy, Ceylon, now Sri Lanka, but died in Australia of a carcinoma in1892, aged 35 when Leslie was just 20 months old. Leslie's father remarried the following year and died of pulmonary tuberculosis in 1897, aged 45.

Following the premature death of both his parents, Leslie and his two younger half sisters were brought up by their aunt Mrs J. Deazeley in Queensland. Leslie was educated locally and at the Brisbane Technical College. He passed the University of Sydney Junior Public Examination, and in 1907 passed the Queensland Public Service Examination. Thereafter he was appointed a Geological Surveyor with the Queensland Department of Mines and spent much of the next three years exploring the Gympie Goldfields and other remote areas of Queensland.

THE AUSTRALASIAN ANTARCTIC EXPEDITION — THE FIRST YEAR

In 1911 Leslie Russell Blake was appointed geologist and surveyor for the Macquarie Island part of the AAE. There he was joined by four other expeditioners — Charles Alfred Sandell, radio mechanic and operator; George Frederick Ainsworth, meteorologist and station leader; Arthur John Sawyer, radio operator; and Harold Hamilton, biologist (pl. 1). They were all young: Ainsworth was the oldest at 33, Hamilton and Sawyer were both 26, Sandell was 25 and Blake just 21.

The Macquarie Island Base was established to relay wireless messages between the Main Base at Cape Denison and mainland Australia. It is worth remembering in light of the subsequent history of the expedition that only these two bases were equipped with both transmitting and receiving sets. The Western Party was supplied with a receiver but it was unserviceable due to missing components, and the S.Y. *Aurora* only had a receiver fitted for her second Antarctic cruise.

With a complement of five the Macquarie Island party was the smallest scientific party then established in the Antarctic region. While they were not the most harmonious group that ever wintered together this can in part be attributed to the smallness of their party and the nature of their duties which limited their opportunities to bond (Dartnall in press). Sawyer and Sandell, the radio operator and mechanic, operated at night when radio reception was best. Indeed, on the foulest nights after they had completed their schedule they would bed down in the radio hut and engine house

PLATE 1

The Macquarie Island Party: (left to right) Charles Alfred Sandell, George Frederick Ainsworth, Arthur John Sawyer, Harold Hamilton and Leslie Russell Blake. Photograph courtesy of the State Library of New South Wales – Home and Away 36150.

on Wireless Hill rather than risk the dark descent to the expedition's hut colloquially known as "the shack". Blake and Hamilton, spent much of their time down the island on field trips away from "the shack", which was the preserve of Ainsworth whose meteorological duties restricted him to the north end of the island.

Personal antipathy apart, the achievements of the Macquarie Island Party were outstanding. Ainsworth established a meteorological station on the isthmus and at 0900 hours on 1 January 1912 commenced taking readings that he continued unabated for the best part of two years. Ainsworth's work was considered important enough for the Bureau of Meteorology to send three men down on the S.Y. *Aurora* to continue it when the AAE men came home. Harold Hamilton made large collections of the flora and fauna that led to a greater understanding of the island's biota. Sawyer and Sandell soon had the wireless equipment installed and quickly established contact with the outside world. Messages for the Meteorological Bureau in Melbourne were transmitted direct or via Hobart, Sydney or Wellington when reception was poor. Contact was made and messages regularly exchanged with Perth (3716 km distant), Port Moresby (some 5118 km distant) and Suva Station, Fiji (4384 km away). They also communicated with H.M.A.S. *Encounter* at a distance of 3500 km, and with various merchant vessels including the German steamer *Adelaide* when it was 1750 km northwest of Perth and with the S.S. *Mataram* when that ship was north of Port Darwin. On 16 April 1912 Sawyer logged the loss of the *Titanic* just hours after it happened (Sawyer 1911–1913).

Two-way communication with the Main Base was not established during the first winter as the aerials at Cape Denison were blown down and could not be re-erected. When the S.Y. *Aurora* next visited – 13 January to 8 February 1913 (second Antarctic voyage) – the seamen on board, with their greater rigging skills, got the aerials up, and successful communication with Macquarie Island was established.

BLAKE'S SURVEYING AND GEOLOGICAL COLLECTION

During his almost two years on Macquarie Island Blake spent much of his time mapping. On the shore of Garden Cove he established a benchmark, which has since disappeared, and with Harold Hamilton's help a measured base line 2830.5 feet (862.7 m) long running NNW across the plateau from a rise on the north side of the top of Gadget Gully. According to Mawson, the survey "was executed as a theodolite triangulation from a measured base line. Sighting poles were erected on all the main features of the land, and these were then plotted systematically. From these established stations the minor details and contours were plotted" (Mawson 1943, p. 16). Given the size of the island, 34 km long and up to 5 km wide, this was a gargantuan achievement especially when the weather is taken into consideration. The hardest part was waiting for periods of good clear weather to do the sightings (pl. 2). Blake's diary entry for 31 October 1912 reads:

> *climbed Mt. Mawson* [now Mt. Hamilton] *and when I had done so another low cloud descended; so I returned to the hut. About noon the cloud lifted so I climbed the mountain "again" and struck a fog this time: (this is the seventh time I climbed this mountain and had no luck). I waited on the top this time for 2 hours and then the fog cleared, so I was able to observe angles from this station* (Blake 1911–1914).

The weather at Macquarie Island can be very variable — changing from calm conditions in bright sunshine to blowing a gale, with driving snow and back to sunshine all within the hour. On other occasions foggy conditions may hang around for days, and gales and storms can last for weeks. All the while Blake collected rocks for his geological collection. Unfortunately, the location of many of his rock specimens are tied to the sighting stations he established that cannot now be identified as his field notebooks are missing (Mawson 1943).

PLATE 2
Blake taking an observation of the sun near the AAE hut on the isthmus. Photograph courtesy of the State Library of New South Wales –Home and Away 36145.

THE SECOND YEAR

The Macquarie Island party had only expected to be away for one year and anticipated going home around April 1913 but tragedy changed that. When Douglas Mawson, Belgrave Ninnis and Xavier Mertz failed to return from their sledging trip, Captain John King Davis, Captain of the S.Y. *Aurora* and second in command of the expedition, made the courageous decision to leave Commonwealth Bay and pick up Wild and the Western party. Captain Davis left six men behind to look for the missing sledgers and thus committed the Macquarie Islanders to a second winter. While it is true that they all volunteered to stay on they really did not have an option (Dartnall in press).

Regular two-way communication between Macquarie Island and the Main Base at Cape Denison was established in February 1913. At first communications were somewhat fragmentary but dramatically improved as the months progressed. Early on Sawyer relayed the story of Mawson's epic survival following the loss of his two companions to an astounded world. Mawson's fantastic struggle against all the odds was, however, completely eclipsed and wiped off the newspapers' headlines a couple of days later by news from New Zealand of the death of Captain Robert Falcon Scott and his four companions on their way back from the South Pole.

The Macquarie Island Party's second year was not without its problems. Equipped and provisioned for a one-year stay their clothing had to be continually patched and repaired, their equipment had to be modified and improvised but most seriously, they ran out of food. They bartered some food stuffs with the sealers who were on the island, but the sealers were in a worse position than the AAE men. Sawyer became sick and disillusioned and when the S.S. *Tutanekai* visited in August 1913 Sawyer went with them leaving Sandell to additionally take on the wireless operator's role.

The S.Y. *Aurora* left Hobart on 19 November 1913 and arrived at Macquarie Island nine days later when the station was handed over to the three men who had come to continue the meteorological observations. Ainsworth, Blake, Hamilton and Sandell were soon packed and ready to leave and within a week they were on their way to pick up Mawson and the overwintering party at Cape Denison. This was duly accomplished, all the while taking soundings and dredging. The *Aurora* then tracked its way westward to the Davis Sea and the Shackleton Ice Shelf, where the Western party had been based, before heading north and home, early in February 1914.

HOME

The *Aurora* docked at Port Adelaide on the afternoon of 26 February 1914. Three days later, on 1 March, there was an official reception in the University of Adelaide Hall, attended by families and friends, and local dignitaries. The Governor-General, Lord Denman, came from Melbourne to convey a message of congratulations from King George V (Mawson 1915). The expedition then dispersed. Less than a month later, Blake was back in his old job as a field assistant with the Queensland Geological Survey. Since there were no expedition funds for further study, his writing up had to take second place to earning a living.

THE GREAT WAR

World events soon overtook the expeditioners. Archduke Franz Ferdinand, heir to the Austro-Hungarian throne, was assassinated on 28 June 1914 in Sarajevo, and five weeks later, on 4 August, Great Britain declared war on Germany. When Blake heard the news he was inland from Bowen, Queensland engaged in geological work. He immediately set out to enlist

and walked 20 miles (32 km) to catch the coach at Bowen only to miss it and then had to trudge the 20 miles back to his camp where he mentally struggled with his duty to the expedition versus his patriotic fervour.

Of the Macquarie Island men only Sandell did not enlist. He was employed doing important work building a new installation in Esperance for Amalgamated Wireless and stayed on afterwards as an operator. Ainsworth became an Intelligence Officer with the Counter Espionage Bureau investigating anti-war groups in Australia. He was promoted to Captain and became Head of the Queensland Branch of the Special Intelligence Bureau, the Australian branch of MI5. Hamilton joined the Royal Navy and became an instructor in the UK. Sawyer joined the Australian Naval and Military Expeditionary Force and served at Rabaul, before enlisting in the Australian Imperial Forces and going on to receive a commission in the Indian Army.

Over the next few months Blake continued to battle with his conscience — weighing his scientific responsibilities versus his patriotism. He contemplated joining Sir Ernest Shackleton's Imperial Trans-Antarctic expedition, though it is not clear if he turned down an invitation from Sir Ernest or just considered applying. In February 1915 he applied for a commission with the Australian Army in the Engineers but heard nothing. Frustrated he tried to enlist in the Artillery some months later. Everything was arranged and he had been recommended for a commission but was surprised and bitterly disappointed to fail the medical. News of the deaths in action at Gallipoli of Bob Bage, who had been the AAE's Astronomer and Assistant Magnetician, and John Firman Deazeley (Blake's cousin) some weeks later, only strengthened his resolve to enlist. He ascertained that he would be accepted by the Army if he underwent a simple operation and there were no complications. This he duly did and on 4 August 1915 became No. 7306 Gunner Leslie Russell Blake (pl. 3). He underwent basic training at the Enoggera Camp in Brisbane, conveniently close to family and his fiancée. His abilities were quickly recognised and he was soon a junior NCO (non-commissioned officer) and drill instructor. He turned down a commission that would have delayed his departure to the front by at least four or five months and left for the Middle East with his fellow recruits. They arrived at Suez just before Christmas by which time the Allies had withdrawn from Gallipoli. Sgt Blake received a field commission on 12 March 1916 just 10 days before his unit left for France.

Like many of the AAE men, Blake took to soldiering, his time south seeming to have been good training for life in the trenches. On 21 July 1916 three divisions of the 1st Anzac Corps moved into the front lines opposite the village of Pozières. Blake went with them volunteering to make a detailed survey of the allied lines from Pozières to Mouquet Farm – an essential prerequisite for an accurate artillery barrage. His brief, to survey the actual lines held by allied troops, sounds innocuous enough but involved venturing into no man's land where he came under enemy fire and indeed he was slightly wounded by a sniper.

Interestingly Blake's military record fails to record his wounding but it is noted in the unit diary and of course in his letters home (Blake 1915–1918). The infantry attack took place at 0030 hours on the morning of 23 July, preceded by a massive bombardment. As a result of his exploits Blake was in due course awarded a Military Cross for his survey which enabled the Australian forces to advance behind a creeping barrage, thereby dramatically reducing

PLATE 3
Studio portrait of 7306 Gunner Leslie Russell Blake, 5th Field Artillery Brigade. Photograph courtesy of the Australian War Memorial, photo P07842.001.

the number of casualties (London Gazette 25 November 1916). The citation reads: "For conspicuous gallantry in action. He carried out reconnaissances under very heavy fire with great courage and determination, obtaining most valuable information". Later that year Blake carried out a similar survey for which he was Mentioned in Sir Douglas Haig's Despatch of 13 November 1916 "for distinguished and gallant services and devotion to duty in the field" (LG 29 December 1916).

In August 1917 he met Frank Hurley, recently back from Shackleton's ill-fated Imperial Trans-Antarctic Expedition and now serving on the Western Front as an Official photographer with the Australian Imperial Forces. Hurley and other war correspondents spent a couple of days in the vicinity. Blake accompanied Frank Hurley and appears in a number of official photographs (pl. 4).

Blake was wounded for a second time less than a month later on 25 September 1917 when a shell fragment some four centimetres long passed clean through his right forearm miraculously passing between the radius and ulna without damaging either bone. He was lucky. Had the piece of shrapnel had a slightly different trajectory or been spinning in a different plane it would have taken his arm off. Blake was sanguine about such matters; he applied a field dressing to his arm and returned to duty. But the wound was serious and the following day he was on his way to "Blighty" and the 3rd London General Hospital at Wandsworth.

PLATE 4

Near Hill 60. Lieutenant L.R. Blake MC standing on the remains of a German reinforced concrete dugout after it had been hit by a 9.2-inch British shell. Photograph courtesy of the Australian War Memorial, photo E00665.

Blake rejoined his unit at the beginning of 1918 when the war was becoming more mobile. His abilities were further recognised when he was posted to Headquarters as a Staff Officer but this did not suit him, he missed the camaraderie of his battery and after a while he requested a transfer back to the 105 Howitzer Battery. His luck finally ran out on 2 October 1918. He was supervising the unloading of an ammunition train behind the lines when a stray artillery shell exploded under his horse. The horse was killed and he was grievously wounded – shrapnel wounds to the left leg and thigh, face and skull. He was conveyed to a nearby Casualty Clearing Station where he died the following morning.

CONCLUSION

Captain Leslie Russell Blake's death just 39 days before peace was declared was a tragedy especially as it appears to have been due to what nowadays we call a "friendly-fire incident" (Dartnall in press). Blake was well aware that he might not survive the war and prior to enlisting had ensured his scientific notes were in safe hands. *The Home of the Blizzard* (Mawson 1915) carried a small version of Blake's map and the Admiralty published a chart of the island in 1917 (chart no. 1022) based on Blake's observations but it was many years before the AAE report appeared. The scientific results of the AAE were published gradually over the following decades and each new report carried an advertisement for Blake and Mawson's *Geology of Macquarie Island*. In the event, the work was not published until 1943, 25 years after Blake's death. It says a lot for both men – the quality of Blake's notes and Mawson's ability to interpret them – that the report was finally published though it is hard to understand why Mawson dropped Blake's name from the authorship (Mawson 1943).

The map that Blake produced of Macquarie Island, and reproduced as a folding map in the back of *Macquarie Island its Geography and Geology* (Mawson 1943), remains his crowning achievement. While he never linked the northern third of the island, north of Sandy Bay, to that of the southern portion to his own satisfaction, his map remained the standard until very recently when satellite imagery, Airborne Synthetic Aperture Radar (AIRSAR) and the global positioning system revolutionised the cartographer's task. Indeed, Blake achieved unbelievably accurate results without these modern aids (Dartnall *et al.* 2001, H. Brolsma pers. comm. 2011).

Blake also collected a large number of geological specimens all of which were correctly identified. However, Blake and Mawson's interpretation of the island's geological history no longer holds sway. They were looking for, and believed that they had found, evidence of glaciation, whereas we now know that Macquarie Island is a block of ocean floor material raised from mid-ocean as a result of severe fault movements and earthquakes that has been subsequently shaped by further faulting, sea-level changes, erosion and periglacial events (Varne *et al.* 2000). Continental drift and the resulting science of plate tectonics that we now use to describe Macquarie Island's formation was first published by Alfred Lothar Wegener in 1915 so that it is highly unlikely that Blake had ever heard of it. For many years it was a contentious theory and only since the 1960s has it been accepted.

The young men who were part of the AAE were an exceptional group and many went on to achieve great things. Tragically for Leslie Blake, Bob Bage, Archibald McLean and at least five of the *Aurora*'s crew, the First World War put an end to promising careers (Lucas 2012, Dartnall in press).

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REFERENCES

Blake, L.R. 1911–14: Diary. Unpublished manuscript, MS 9551. Melbourne: State Library of Victoria, La Trobe library; Adelaide: Mawson Antarctic Collection, Coach House, Waite Institute, University of Adelaide.

Blake, L.R. 1915–18: Letters and Postcards home. Unpublished, 1DRL/0128. Australian War Memorial.

Dartnall, H.J.G. 2008a: Antarctic Vignettes 1: Mawson's Sailmaker – James Forbes. *Papers and Proceedings of the Royal Society of Tasmania.* **142**(2): 45–46.

Dartnall, H.J.G. 2008b: Antarctic Vignettes II: The search for S. Tasman, AB on the *Terra Nova*, 1903–04. *Papers and Proceedings of the Royal Society of Tasmania.* **142**(2): 47–48.

Dartnall, H.J.G. 2009a: Antarctic Vignettes III: Shackleton's AB – William Frederick Williams. *Papers and Proceedings of the Royal Society of Tasmania.* **143**(2): 83–86.

Dartnall, H.J.G. 2009b: Antarctic Gold: Chief Petty Officer Albert Balson BEM*, DSM, RN. *The Review, Quarterly Journal of the Naval Historical Collectors and Research Association.* **22**(1): 4–10.

Dartnall, H.J.G. 2011: Antarctic Vignettes: Dr. Wilson's Assistant – Horace Edgar Buckridge. *Journal of the Orders and Medals Research Society.* **50**(1): 42–45.

Dartnall, H.J.G. in press: *Lost in the Mists: Leslie Russell Blake – Mawson's Cartographer, Hero of Pozières.* Australian Scholarly Publishing, Melbourne.

Dartnall, H.J.G., Ward, N., Selkirk, P.M., Adamson, D.A. & Pharaoh, M. 2001: The influence of L.R. Blake, pioneering sub-Antarctic geographer and geologist, on the topographic mapping of Macquarie Island. *Polar Record* **37**(201): 143–150.

Lack, J. 1983: Hoadley, Charles Archibald Brookes. *In: Australian Dictionary of Biography 1891-1939.* Melbourne University Press, Melbourne **9**: 313–314.

Lucas, A. 2012: Mertz in Hobart: impressions of one of Mawson's men while preparing for Antarctic adventure. *Papers and Proceedings of the Royal Society of Tasmania* **146**: 37–44.

Mawson, D. 1915: *The Home of the Blizzard.* 2 Volumes. William Heinemann, London: Vol. 1: 349 pp. and Vol. 2: 338 pp.

Mawson, D. 1943: Macquarie Island its Geography and Geology. *Australasian Antarctic Expedition 1911-14 Scientific Reports*, Series A Volume V: 194 pp.

Price, B. 2005: Watson, Andrew Dougald. *In: Australian Dictionary of Biography 1580–1980.* Melbourne University Press, Melbourne Supplement: 398.

Sawyer, A.J. 1911–13: Diary. Unpublished manuscript, MSS. 383. Sydney: State Library of New South Wales, Mitchell Library.

Varne, R., Brown, A.V. & Fallon, T. 2000: Macquarie Island: its geology, structural history and the timing and tectonic setting of its N-MORB to E-MORB magmatism. *In* Dilek, Y., Moores, E., Elthon, D. & Nicolas, A. (eds): Ophiolites and oceanic crust: new insights from field studies and the Ocean Drilling Programs. *Geological Society of America.* Special Paper **349**: 301–320.

Wegener, A.L. 1915: *Die Entstehung der Kontinente und Ozeane. [The Origin of Continents and Oceans].* Friedrich Vieweg & Sohn Akt. Ges, Braunschweig: 367 pp.

Wilcock, A.A. 1990: Stillwell, Francis Leslie. *In: Australian Dictionary of Biography 1891-1939.* Melbourne University Press, Melbourne. **12**: 94–95.

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EXTREME PHYSICAL EVENTS IN THE SUB-ANTARCTIC

by Patrick G. Quilty

(with seven text-figures and two plates)

QUILTY, P.G. 2012 (14:xii): Extreme events in the sub-Antarctic. *Papers and Proceedings of the Royal Society of Tasmania* 146: 63–69. ISSN 0080-4703. School of Earth Sciences, and Institute of Marine and Antarctic Studies (IMAS), University of Tasmania, Private Bag 79, Hobart, Tasmania 7001, Australia. Email: P.Quilty@utas.edu.au

Extreme physical events, excluding meteorological events, can be divided into two broad categories — endogenous and exogenous. Endogenous phenomena include earthquakes, landslides, tsunami, volcanic or gas hydrate eruptions that occur within the region but may have both local and distant impacts; the 2011 Puyehue-Cordon Caulle volcanic eruption, and the frequent major earthquakes along the Chile margin or near Macquarie Island are examples. Exogenous events are those originating outside the area but influencing it. These include the terminal Cretaceous asteroid impact, asteroid/meteorite impacts, such as the major *Eltanin Asteroid* impact 2.5 million years ago, and extraterrestrial-sourced radiation from extreme solar/galactic or extra-galactic events in which the effect is not confined to the sub-Antarctic but is global.

Key Words: sub-Antarctic, volcanic eruptions, earthquakes, landslides, gas hydrates, asteroid/meteorite impacts, space weather.

INTRODUCTION

The sub-Antarctic is now recognised as a separate realm (Green 2007), differing from the glacial realm to its south and the temperate realm to its north. It is a uniquely Southern Hemisphere feature covering some 8% of the Earth's surface and linking the southern extremities of the three great oceans – Indian, Pacific and Atlantic (fig. 1). This paper discusses the concept of extreme events in the realm, events that are out of the range of normally expected or experienced occurrences. It concentrates on the non-meteorological extreme events and distinguishes those events that are endogenous (generated within the realm) and exogenous (those that impact from outside the realm). Examples of the former are volcanic eruptions and landslides, and the latter, mainly space-sourced events such as extreme cosmic ray fluxes or meteoritic impacts.

ENDOGENOUS EVENTS AND THEIR CONTROL

Endogenous events are those generated within the realm itself or internally in the Earth and are easily recognised as such. These include earthquakes, volcanic eruptions, landslides and tsunami. While discussed separately here, there are marked interactions between the events; for example, volcanic eruptions can give rise to earthquakes, landslips and tsunami.

Earthquakes

There are many mechanisms for the generation of earthquakes and some generalisations can be made. Most are small (> or =3 on the Richter Scale) at mid-ocean ridges, mainly on transform faults that cut, and are perpendicular to, the ridge crests (fig. 2). They also are shallow (generally <30 km below the Earth's surface). In marked contrast are those characteristic of subduction zones. In the sub-Antarctic, the most likely regions are the Scotia Arc (fig. 3) where the Atlantic Ocean seafloor is subduced below the Antarctic plate, and the southwestern margin of South America, close to the source of the world's strongest recorded earthquakes. Here, the Pacific Plate descends to depths of almost 700 km and generates deep and very high-energy earthquakes. Movement along these zones may be *continuous* (a few cm per year when many small earthquakes of little significance may be generated) or *intermittent* (when movement is halted by friction for long periods, only to be released dramatically when the locked condition is overcome; major disasters in the last few years were of this type). Because there is a large vertical component to the movement, major tsunami are a feature of this type of earthquake.

An unusual site is that on Macquarie Ridge near Macquarie Island where, in an oceanic setting, two plates collide obliquely. The Indian-Australian Plate is moving due north at about 6 cm per year, and to its east the Pacific Plate is moving slightly west of north. The region regularly experiences large earthquakes that are basically of one slab sliding past another but tsunami are minor. Earthquakes of magnitude 7 occur almost every year.

While transform faults generally produce small earthquakes, there was an exception in March 1998, when, by that time for the year, the largest earthquake on Earth (8.1) occurred at the southern end of one of these features (fig. 4). It was at 62°49.56'S; 149°40.26'E, at a depth of 10 km and was most unexpected in that setting.

Volcanic eruptions

Most islands in the sub-Antarctic are volcanic in origin and much of that volcanism is basaltic in composition and expression. They are thus expected to be subject to quiet eruptions. An exception is the Scotia Arc or South Sandwich Islands, linking the northeastern end of the Antarctic Peninsula to South America (fig. 3). This is the only region of the Antarctic Plate where subduction is active, leading Atlantic Ocean seafloor dipping steeply westwards at 75° beneath the small Sandwich Plate. Quilty (2007) provided a summary of activity in the region. It is likely that subduction has been active and continuous for the last 15 Ma (Leat *et al.* 2007). The volcanoes are typical of those found over such subduction zones elsewhere but have their own characteristics.

In 1962, there was a previously unrecorded event when Protector Shoal (previously unknown with its summit at

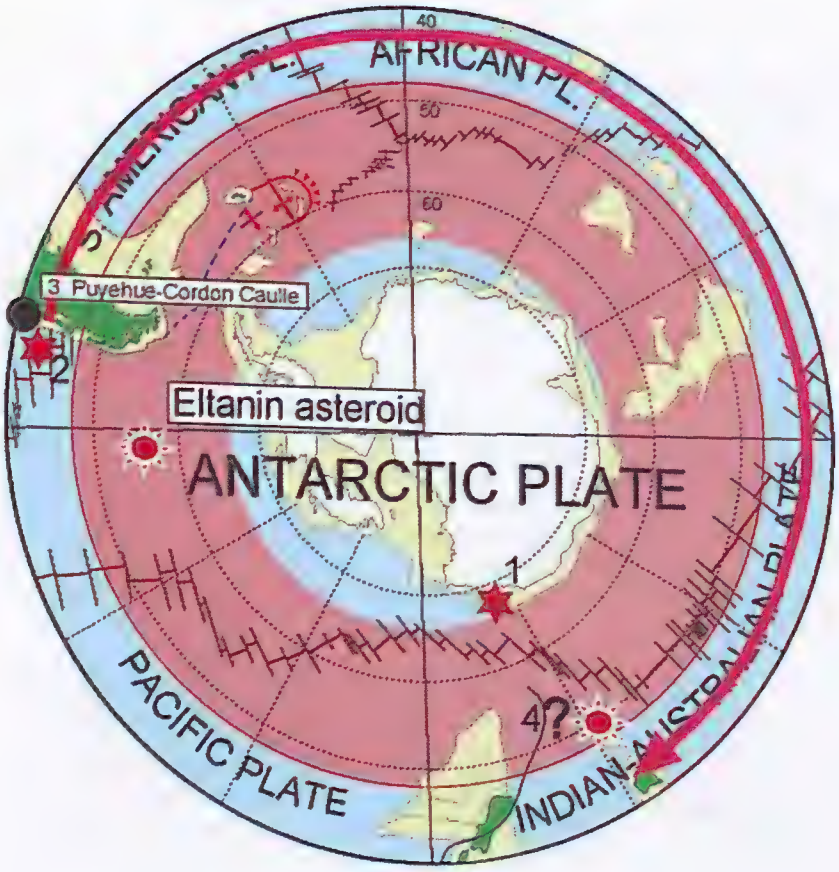

FIG. 1 — Modern Antarctica showing major tectonic features and location of some events mentioned in text. Sub-Antarctic realm indicated in deep pink. 1. Record of the largest earthquake on Earth known from the first three months of 1998. 2. The site near Chile of the largest earthquake recorded on Earth. 3. Site (black filled circle) of volcano Puyehue-Cordon Caulle that erupted in 2010 causing major disruption to Southern Hemisphere air travel. Travel direction around Southern Hemisphere indicated. 4. Site of possible impact site close to Tasmania. Eltanin asteroid impact site also shown.

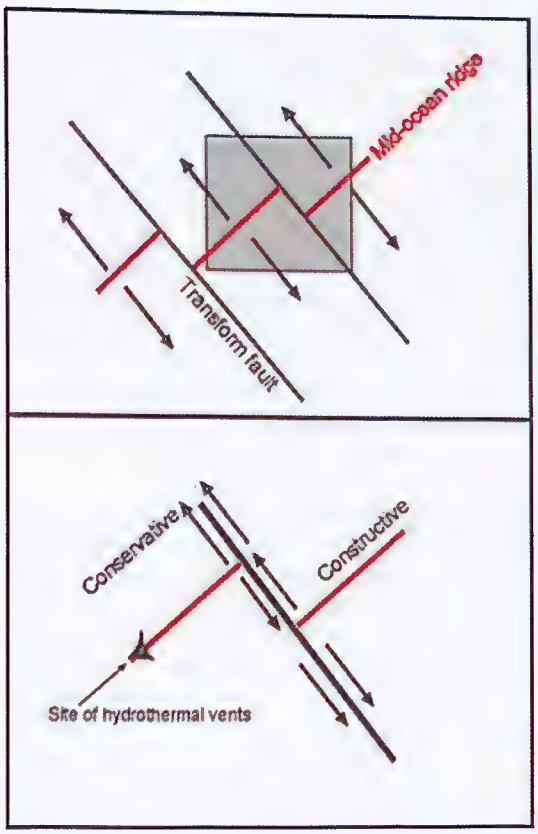

FIG. 2 — Geometry of transform faults.

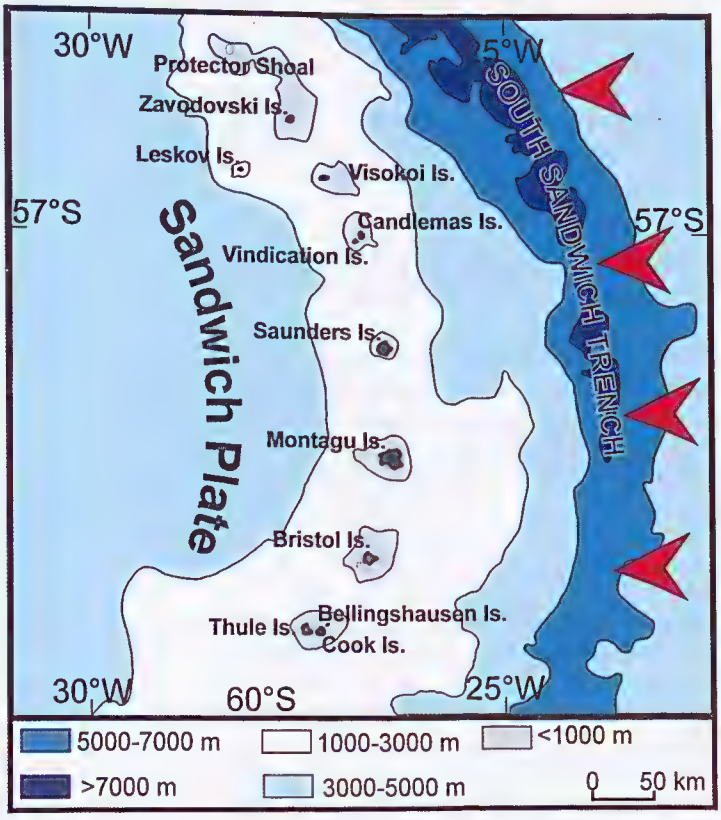

FIG. 3 — Setting of South Sandwich Islands illustrating subduction of South Atlantic tectonic plate beneath the Antarctic plate.

27 m below sea level) erupted a vast raft of pumice (Gass *et al.* 1963, Sutherland & Olsen 1968). That raft circled the Southern Hemisphere for many years, slowly becoming more dispersed, the fragments smaller, and providing glass shards to the seafloor to contribute to the sediment. Some of the floating fragments initially were as large as about one metre in diameter and accumulated particularly on the western side of Southern Hemisphere landmasses.

The eruption perhaps provides another mechanism for transport of vegetation propagules around the region, a means of colonising new islands. Such large fragments may remain on island margins for many years, and because they are so large, may become vegetated. Storm activity may then remove them, and currents carry them normally eastwards until they come aground on a new location where they bring new vegetation and marine species that became established en route.

The recent eruption of Puyehue-Cordon Caulle (pl. 1) is an example of an eruption that, while not very extreme in volcanic eruption terms, is big enough to have had a widespread effect on Southern Hemisphere economies, particularly by disrupting air services. Strictly, it is outside the sub-Antarctic at 40°25'S, but the plume apparently did flow into the sub-Antarctic regions.

Tsunami

Many of the events discussed throughout this paper may generate tsunami. Volcanic eruptions, earthquakes and major downslope land movements are recognised from well-documented experience elsewhere as causing tsunami. There are ample recent examples in the public mind.

"Landslides", gas hydrates and related phenomena

Landslides: The area available for traditional subaerial landslides in the sub-Antarctic is very small – some 6500 km² (excluding Îles Kerguelen and some more northerly islands); however, land movements are occurring. Quilty (1989) reviewed the landslide issue for the Antarctic and included comments on the sub-Antarctic. Several factors make this worth re-examining. First, many of the landmasses, while small, are steep-sided and composed of friable debris. Second, the projected direction of climate change indicates that the region will warm, and the regolith is likely to become more unstable as groundwater availability increases. Plate 2 illustrates the scale and potential impact of landslides on steep slopes, in this case at Lusitania Bay, Macquarie Island.

Island margin collapse: Gough Island has evidence of large-scale collapse structures that have left a series of arcuate scars (fig. 5). The island formed over the last million years and the scars suggest that collapse events occur every 200 000 years or more often. These events are major earth movements and could be expected to generate significant tsunami, depending on whether or not they were essentially instantaneous or occurred slowly. Bouvet Island shows evidence of collapse to the northwest. St Paul Island has an almost straight northeast margin where part of the island has disappeared but whether this is simple large-scale landslip or tectonically controlled faulting is unclear (fig. 6).

It is already clear that major landslips have occurred on Heard Island (Quilty 2007) where a scar on the southwest flank is the site of a debris avalanche, leaving behind the escarpment in which the small active volcano of Mawson Peak developed (fig. 7). The ocean is shallow to the southwest of the island, marking the site of deposition of the avalanche content. The age and repeat frequency of such events are unknown but many of the sub-Antarctic islands are volcanic in origin with steep sides and this relatively large-scale phenomenon can be expected to recur.

On a much smaller scale is the continuing gentle downslope movement of regolith on the flanks of the islands or steep geomorphic features, and marginal to lakes.

Turbidity currents/debris flows: What is unknown is the scope for major submarine downslope movements adjacent to Antarctica and the islands. It is apparent that all islands and the continent have steep sides that extend into the deep ocean and there are likely to be submarine canyons at approximately the same concentration as in other parts of the world where they have been studied in more detail. Such canyons are active conduits for the slumping of sediment from shallow to deep water and are important in geological history. They are well-known as affecting human installations such as submarine cables (Heezen & Ewing 1952).

Gas hydrates: Seismic studies around the Antarctic have identified Bottom Simulating Reflectors (BSR), the result of

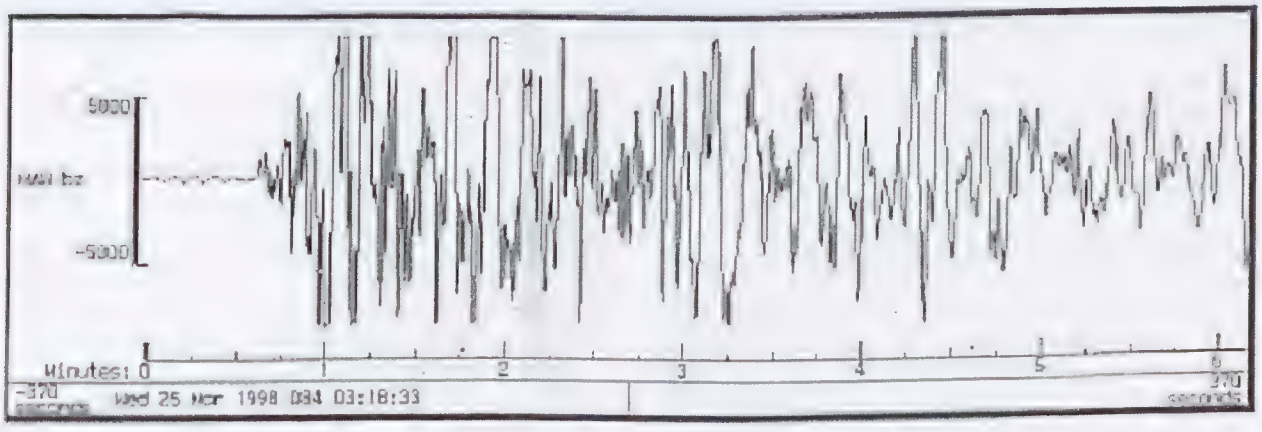

FIG. 4 — Record of the largest earthquake on Earth for the first three months of 1998. Locality indicated on fig. 1.

PLATE 1
Volcano Puyehue-Cordon in eruption, 2010. Locality indicated on fig. 1. Image courtesy of Larry Lackey.

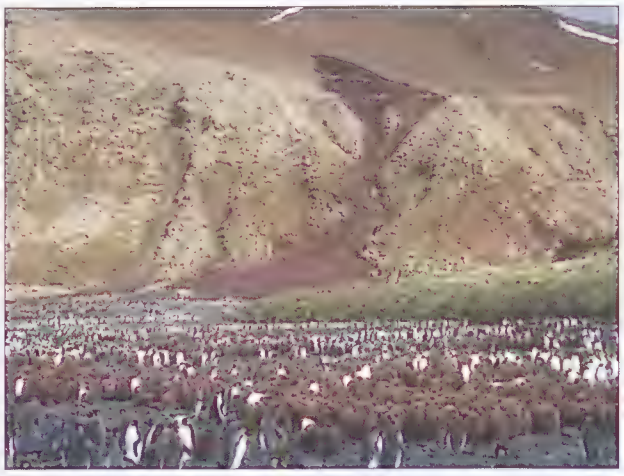

PLATE 2
Landslide at Lusitania Bay, Macquarie Island. Image courtesy of Noel Carmichael.

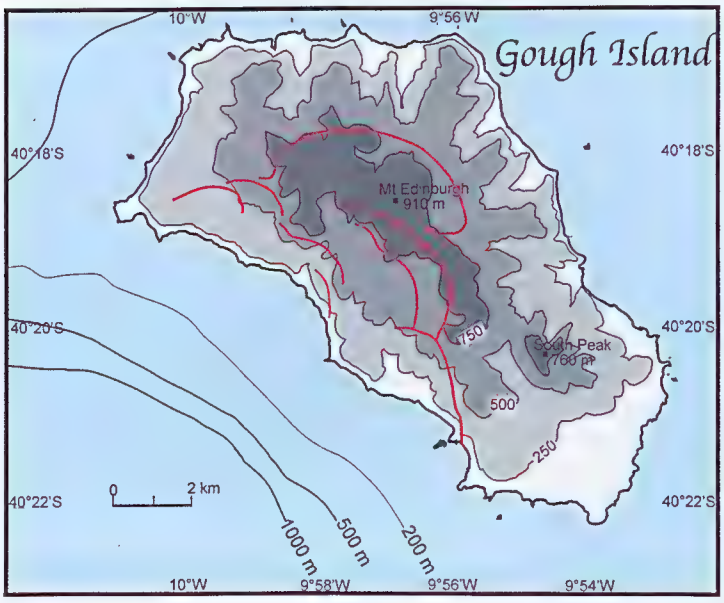

FIG. 5 — Major landslips on Gough Island, South Atlantic Ocean. Periodically, large slabs of the island slide into the Atlantic Ocean, controlling much of the island's topography.

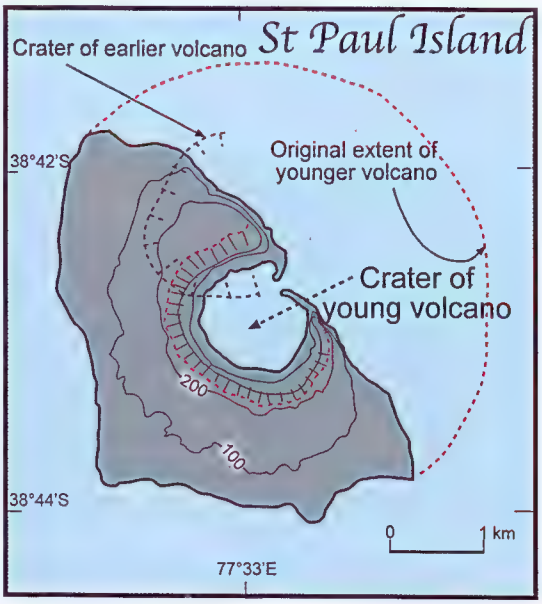

FIG. 6 — St Paul Island, Indian Ocean, showing how northeast margin of the island is controlled by either landslip or fault movement.

the existence of gas hydrates or methane hydrates, usually at 300–500 m below the seafloor. Gas hydrates are regarded by some as the major reservoir of methane on Earth. They are only metastable due to low temperature and the pressure of water above. A concern to some in the climate change science community is that changes in oceanic parameters (especially temperature) may overcome the metastability causing the release of the methane. This possibility is taken by many (e.g., Svensen *et al.* 2004) to be the likely cause of the Paleocene/Eocene Thermal Maximum (PETM) at 55 million years (Paleocene/Eocene boundary) when the largest ^{12}C excursion known led to a great increase in global temperatures and a major extinction event. Of course, such an event would be global but the sub-Antarctic would be included in the effects.

It is thought that some modern continental margin collapses may be due to this feature and thus it is possible that the Antarctic continental margin (especially because it is so deep) could be affected providing significant flows of sediment to the deep ocean floor of the sub-Antarctic.

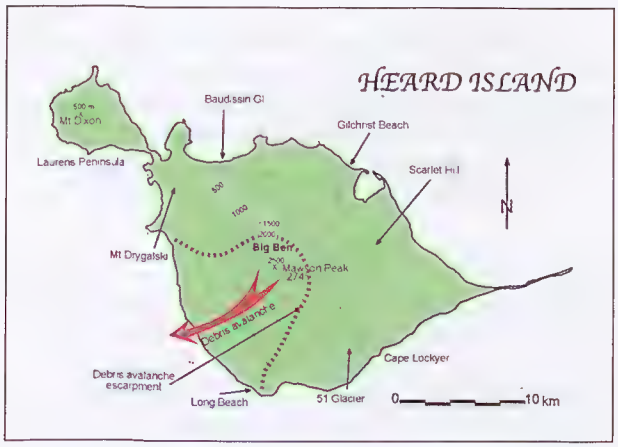

FIG. 7 — Heard Island, south central Indian Ocean, showing site of debris avalanche that removed a large slab of the island and deposited it to the southwest.

Magnetic field reversals/geomagnetic excursions

It is well known that the Earth's magnetic field reverses from time to time, the most recent at about 750 ka. The pattern is now well documented and is used routinely in analysis of cores taken by scientific drilling programs such as the Ocean Drilling Program (ODP). This phenomenon is global in its effects and this makes it valuable as a dating technique.

What is less well known and understood is the phenomenon of geomagnetic excursions, the last one of significance at about 40 ka and recorded in ice cores – the Laschamp event (Guillou *et al.* 2004). During such an excursion, the field strength can fall to less than 20% of normal and the orientation of the field can vary for up to about 7000 years, by 45°. This disorientation can be regional and sometimes global. The causes are unclear and there are a few hypotheses. One hypothesis is that the cause lies in the outer core of the Earth which is liquid of very low viscosity, where field lines are thought to become "tangled" (Gubbins 1999). An alternative hypothesis suggests that the cause is tectonic, due to changes in the core/mantle boundary induced by some deep subduction control, by impacts, or by events at mantle plume generation. Some aspects of the latter hypothesis make sense in relation to regionalisation of the result.

EXOGENOUS EVENTS

Exogenous events are those generated outside the region, or even dominantly, the Earth, and which cannot, as yet, be predicted. Included here particularly are space-related events such as meteorite impacts, solar influences and cosmic ray phenomena. Any effects in the sub-Antarctic are only part of global impact.

Meteorites/asteroid impacts

Space is a source of some sediment in the region but its contribution is swamped by "normal" sedimentation, and hardly extreme. By contrast, meteorites and related impacts do constitute extreme events and, although observational data for the region are very few due to lack of exploration, there is evidence that impacts have occurred and it is possible to make estimates of the likely rate and size of those impacts

In the mid-1960s, USNS *Eltanin* recovered Core 13-4 (57°47.2'S; 90°47.6'W; 4700 m water depth) which incorporated asteroidal debris and led to further detailed examination of the area in the 1990s and currently. Gersonde *et al.* (1997 *et seq.*) reported further on the site, following a major expedition to the region, and were the first to analyse evidence for this major asteroid impact in the Southern Ocean – the Eltanin asteroid (fig. 1). This was dated at c.2.5 Ma (late Pliocene or now earliest Pleistocene) and estimated to have had a diameter of 1–4 km. Evidence is now known from an area over 1000 km wide. At 1 km the impact is estimated to have caused a 20–40 m tsunami on the South American/Antarctic coasts and was used as a possible explanation for some apparently unusual sediment distribution on East Antarctica. If the diameter was 4 km, the tsunami may have been 10–25 times as great but would decay quickly. When discovered, it was the first record of a major impact in the world's oceans. As the chances of an asteroid of 10 km diameter hitting the Earth is only $1:10^8$ years, it is likely that only one or two such craters exist on the modern seafloor.

Ocean Drilling Program Leg 189 (Exon *et al.* 2001) recorded 58 microtektites in a sample from Site 1169 on the west flank of the South Tasman Rise and Kelly & Elkins-Tanton (2004) suggested that they represent evidence of a late Miocene impact (site unknown and date not precise but likely to be about 5–10 Ma) and an event separate from any that deposited the well-known australites of Australia.

In March 2007, there was a report of space junk (experts suggested a meteorite) seen from a Lan Chile flight over the Southern Ocean.

Other space sourced influences

Solar

The regular 11-, or more strictly 22-, year sunspot cycle is well-recognised, but occasionally the sun produces extreme events.

In 1859, the British solar astronomer Richard Carrington witnessed what may have been the most extreme solar phenomenon over the past 500 years (Carrington 1859, Hodgson 1860, Tsurutani *et al.* 2003). Carrington had a private observatory devoted to the sun and projected a solar image onto a screen. At 11.18 am on 1 September 1859, he was surprised to see an enormous group of sunspots suddenly erupt into a white, kidney-shaped feature. The event lasted for about five minutes and by 11.23 am had passed. It was thus large enough to be seen by the naked eye. It is now known as a *white light solar flare* and generated a flux of particles known as a *Coronal Mass Ejection* or CME.

The effects were several. The next day, the Earth was subject to red and green aurorae (including contemporary reports of purple), so strong that newspapers could be read before dawn and the auroras were even visible close to the tropics. Telegraph systems were severely disrupted and spark discharges from instruments set fire to telegraph paper.

On 6–19 March 1989, but especially on 13–14 March, was another such solar magnetic storm (Kurth 1991) and it was fortunate for humanity or planet Earth that it was directed largely away from Earth and directed away from one side of the sun. The event caused the power supply

to six million Canadians to be turned off due to damage to production facilities. It is unclear how much damage was done to welds in major pipelines such as the Trans-Alaska pipeline because the event caused a major generator and, consequently, current-cancelling systems, to fail. The heating of the upper atmosphere induced by the CME led to increased atmospheric drag on spacecraft, and satellites dropped to lower orbits so that their orbits had to be re-calculated. GPS and such systems were inoperative for some 10 minutes. It has been estimated that such a flare could do some $30–$70 billion damage to space facilities if it occurred now.

It is completely unknown what damage was done to the Mir Space Station or its inhabitants. March 1989 was an active month for the sun with major activity on 13 March with lesser phases on 26–29 and 23 March. Effects were seen by the author from the Australian Antarctic supply ship MV *Icebird* south of Western Australia in broad daylight on 23 March 1989 and expressed as shimmering in the sky. Data for the period are available at: http://wdc.kugi.kyoto-u.ac.jp/index.html

There was another such event in 2001 and as instrumental observations have increased greatly in recent years, much more is known of this rather than of earlier events.

Two spikes in ^{10}Be occurred in ice cores from the Antarctic at 60 000 and 35–40 000 years (Raisbeck *et al.* 1987). The origin is cosmic ray impact but what the event was that caused the development of ^{10}Be is unknown.

Galactic/Extragalactic

Supernovae produce an intense flash of gamma rays and ultraviolet light and that travels very rapidly as electromagnetic radiation. Particles travelling much more slowly arrive later, even hundreds of thousands of years later. The last supernova detected in our galaxy was noted in 1604.

Extragalactic events are rarer but are known as "bursters" and generate intense, long-lived gamma ray bursts. One possible source is hypernovae (a particular form of very large supernova) from the death of very large hydrogen/helium stars. These occurred within the first billion or so years of the Big Bang at the beginning of the universe and are still detected. They are the oldest detectable events in the universe.

These events, collectively known as space weather, impact on the outer atmosphere causing chaos to communications systems, and in modern days, damage satellites, their inhabitants, and electronic facilities.

EVENTS IN THE LONG TERM

The following events can be classed as exogenous, one due to asteroid impact at a distant location, and the others as possibly global events with some sub-Antarctic contribution.

Oceanic Anoxic Events (OAEs)

During the Cretaceous, there were intervals of globally high temperature, enhanced Greenhouse conditions, and altered oceanic circulation patterns different from the modern thermohaline pattern. Three major, and several lesser, intervals are well-recognised. The major events are the Oceanic Anoxic Events (OAE 1-3) (Jenkyns 1980, Gertsch *et al.* 2010). Indian Ocean Cretaceous sediments reflect in part the influence of these events.

The marine environment was characterised by a stratified ocean which allowed the accumulation of organic-rich dark sediment and markedly reduced benthic activity. The organic-rich nature of the sediments has been invoked as a partial explanation for hydrocarbon generation.

Terminal Cretaceous asteroid impact

The seafloor and some island areas of the sub-Antarctic include rocks that are old enough to have experienced events that appear to be unique. Extinctions and climate change that were the defining events of the Cretaceous/Cenozoic transition were a result of a major asteroid impact on the Yucatan Peninsula in the Gulf of Mexico (Alvarez *et al.* 1980, Hildebrand *et al.* 1998). This event had global significance as the control on one of the major extinction events in global history, that at the end of the Cretaceous.

Paleocene/Eocene Thermal Maximum (PETM) – possible gas hydrate release

A major excursion in ^{12}C, the lighter isotope of carbon, in marine plankton skeletons marks the Paleocene/Eocene transition (55 Ma) and appears unique in the time span (mid-Cretaceous-Recent) for which records can be determined. It appears to have been caused by a massive release of methane (Dickens *et al.* 1997) into the atmosphere over a geologically short interval, sometimes quoted as being as short as 1000 years. It resulted in a geologically short-lived (recovery period of some 200 000 years; Röhl *et al.* 2007) but sharp increase in global sea and atmosphere temperature by as much globally as 6°C, higher in polar regions (Greenhouse conditions), in turn leading to significant extinction of marine benthos (Thomas & Shackleton 1996). The cause of the release of methane is not fully determined but gas hydrates from below the seafloor are commonly quoted as a source and the North Sea has been suggested as the site of release.

CONCLUSIONS

The sub-Antarctic is subject to extreme events although the low population and observatory level makes their record less than perfect.

Endogenous events such as earthquakes, volcanic eruptions and their side effects (landslides, tsunami) can be monitored from elsewhere but are generated within the sub-Antarctic and their major impacts are felt there. Exogenous events from space are dominantly those affecting the entire world but also the sub-Antarctic, and are mainly solar or galactic in origin. Asteroid/meteor impacts are mainly from within the solar system.

With better understanding of the dynamics of planet Earth, endogenous events may become predictable but this is unlikely for most exogenous events.

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realm is the subject of dedicated biennial conferences held in Hobart, Tasmania, since 2007 and the major distinguishing features have been identified. This paper was delivered to the Third sub-Antarctic Forum, 1–2 August 2011. I thank the organisers for the opportunity to express these ideas. I thank Drs M. Coffin and M. Duldig for constructive reviews.

REFERENCES

Alvarez, L.W., Alvarez, W., Asaro, F. & Michel, H. 1980: Extraterrestrial cause for the Cretaceous/Tertiary extinction. *Science* **208,** 1095–1108.

Carrington, R.C. 1859: Description of a singular appearance seen in the sun on September 1, 1859. *Monthly Notices of the Royal Astronomical Society* **20**: 13–15.

Dickens, G.R., Castillo, M.M. &Walker, J.C.G. 1997: A blast of gas in the latest Paleocene: simulating first-order effects of massive dissociation of oceanic methane hydrate. *Geology* **25**(3): 259–262.

Exon, N.F., Kennett, J.P. & Malone, M.J. (eds) 2001: The Tasmanian Gateway: Cenozoic climatic and oceanographic development. Proceedings of the Ocean Drilling Program, Initial Reports 189. Texas A&M University, College Station TX: http://www.odp.tamu.edu/publications/189_IR/189ir.htm.

Gass, I.G., Harris, P.G. & Holdgate, M.W. 1963: Pumice eruption in the area of the South Sandwich Islands. *Geological Magazine* **100**: 321–33.

Gersonde, R., Kyte, F.T., Bleil, U., Diekmann, B., Flores, J.A., Gohl, K., Grahl, G., Hagen, R., Kuhn, G., Sierro, F.J., Völker, D., Abelmann, A. & Bostwick, J.A. 1997: Geological record and reconstruction of the late Pliocene impact of the Eltanin asteroid in the Southern Ocean. *Nature* **390**: 357–363.

Gertsch, B., Adatte, T., Keller, G., Tantawy, A.A.A.M., Berner, Z., Mort, H.P. & Fleitmann, D. 2010: Middle and late Cenomanian oceanic anoxic events in shallow and deeper shelf environments of western Morocco. *Sedimentology* **57**: 1430–1462.

Green, G. 2007: Afterword. *Papers and Proceedings of the Royal Society of Tasmania* **141**(1): 181.

Gubbins, D. 1999: The distinction between geomagnetic excursions and reversals. *Geophysical Journal International* **137**(1): F1–F4.

Guillou, H., Singer, B.S., Laj, C., Kissel, C., Scaillet, S. & Jicha, B.R. 2004: On the age of the Laschamp geomagnetic excursion. *Earth and Planetary Science Letters* **227**: 331–343.

Heezen, B.C & Ewing, M. 1952: Turbidity currents and submarine slumps and the 1929 Grand Banks earthquake. *American Journal of Science* **250**: 849–873.

Hildebrand, A.R., Pilkington, M., Ortiz-Aleman, C., Chavez, R.E., Urrutia-Fucugauchi, J., Connors, M., Graniel-Castro, E., Camara-Zi, A., Halpenny, J.F. & Niehaus, D. 1998: Mapping Chicxulub crater structure with gravity and seismic reflection data. *In* Grady, M.M., Hutchison, R., McCall, G.J.H. & Rothery, D.A. (eds): *Meteorites: Flux with Time and Impact Effects*. The Geological Society, London: 155–176.

Hodgson, R. 1860: On a curious appearance seen on the sun. *Monthly Notices of the Royal Astronomical Society* **20**: 15–16.

Jenkyns, H.C. 1980: Cretaceous anoxic events – from continents to oceans. *Journal of the Geological Society* **137**: 171–188.

Kelly, D.C. & Elkins-Tanton, T. 2004: Bottle-green tektites from the South Tasman Rise: deep-sea evidence for an impact event near the Miocene/Pliocene boundary. *Meteoritics and Planetary Science* **39**: 1921–1929.

Kurth, W.S. 1991: The great solar storms of 1989. *Nature* **353**: 705–706.

Leat, P.T., Larter, R.D. & Millar, I.L. 2007: Silicic magmas of Protector Shoal, South Sandwich arc: indicators of generation of primitive continental crust in an island arc. *Geological Magazine* **144**: 179–190.

Quilty, P.G. 1989: Landslides: extent and economic significance in Antarctica. *In* Brabb, E.E. & Harrod, B.L. (eds): *Landslides: Extent and Economic Significance in the World.* A.A. Balkema, Rotterdam: 127–132.

Quilty, P.G. 2007: Origin and evolution of the sub-Antarctic Islands: the foundation. *In* Selkirk, P., Quilty, P.G. & Davies, M. (eds) *The sub-Antarctic. Papers and Proceedings of the Royal Society of Tasmania* **141**(1): 35–58.

Raisbeck, G.M., Yiou, F., Bourles, D., Lorius, C., Jouzel, J. & Barkov, N.I. 1987: Evidence for two intervals of enhanced ^{10}Be deposition in Antarctic ice during the last glacial period. *Nature* **326**: 273–277.

Röhl, U., Westerhold, T., Bralower, T.J. & Zachos, J. C. 2007: On the duration of the Paleocene-Eocene thermal maximum (PETM). *Geochemistry Geophysics Geosystems* **8**(12): Q12002, doi: 10.1029/2007GC001784.

Sutherland, F.L. & Olsen, A.M. 1968: The persistence of drift pumice, from the 1962 South Sandwich Islands eruption, in southern Australasian waters. *Papers and Proceedings of the Royal Society of Tasmania* **102**: 1–5.

Svensen, H., Planke, S., Malthe-Sørenssen, A., Jamtveit, B., Mykelbust, R., Eidem, T.R., & Rey, S. 2004: Release of methane from a volcanic basin as a mechanism for initial Eocene global warming. *Nature* **429**: 542–545.

Thomas, E. & Shackleton, N.J. 1996: The Paleocene-Eocene benthic foraminiferal extinction and stable isotope anomalies. *Geological Society London Special Publications* **101**(1): 401.

Tsurutani, B.T., Gonzalez, W.D., Lakhina, G.S. & Alex, S. 2003: The extreme magnetic storm of 1–2 September 1859. *Journal of Geophysical Research* **108**(A7), 1268 doi: 10.1029/2002JA009504

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PLATEAU VEGETATION ON SUB-ANTARCTIC MACQUARIE ISLAND

by P.M. Selkirk

(with one text-figure, one plate and two tables)

SELKIRK, P.M. 2012 (14:xii): Plateau vegetation on sub-Antarctic Macquarie Island. *Papers and Proceedings of the Royal Society of Tasmania* 146: 71–79. ISSN 0080-4703. Department of Biological Sciences, Macquarie University, Sydney, NSW 2109, Australia. Email: pselkirk@pip.com.au

The plateau of sub-Antarctic Macquarie Island supports an open short herb, feldmark vegetation that is markedly affected by the prevailing strong westerly winds. This paper reports on a line transect survey carried out in 1980 which documents variation then apparent in species composition in this vegetation. Sixty-two species were recorded, with plant occurrences along 16 transects ranging from 16.7–99.5%. The cushion plant *Azorella macquariensis* Orchard was an important component of the plateau vegetation: it occurred at 14 of the 16 sites surveyed, with occurrences up to 50%. The dieback reported in *Azorella macquariensis* in 2008 was, by 2012, regarded as extensive and severe throughout its range. The data presented here well precede the first records of the dieback, and contribute to early descriptive data against which future developments in the plateau vegetation of Macquarie Island can be evaluated.

Key Words: sub-Antarctic, Macquarie Island, feldmark, *Azorella macquariensis*, dieback.

INTRODUCTION

In a part of the world that is principally ocean, sub-Antarctic land is a rare resource. The few sub-Antarctic islands support extremely interesting vegetation, rare on the world scale. Macquarie Island, 158°55'E; 54°30'S, is no exception. Its flora is known to include 47 species of vascular plants of which four are endemic (*Flora of Australia* 1993, Clements & Jones 2007), 86 species of mosses (Seppelt 2004, Ochyra *et al.* 2008) and 51 species of liverworts (Selkirk *et al.* 1990). Its treeless vegetation ranges from tall tussock grasses on coastal slopes to an open, discontinuous short herb, tundra-like vegetation, known as feldmark, on the island's plateau above about 200 m (Carmichael 2007, Selkirk 2007, 2009). In the cool, cloudy, moist sub-Antarctic climate this distinctive vegetation is strongly affected by the extremely windy conditions, blowing predominantly from the west and northwest (Bureau of Meteorology 2012).

Macquarie Island's earliest human visitors were seafarers concerned with the seal fur and oil trades, but once its location became known in 1810, Macquarie Island and its vegetation became of interest to explorers and scientists. In 1894 Professor A. Hamilton of the University of Otago spent two weeks on the island, long enough to visit parts of the plateau. He wrote: "The tussocks and the *Stilbocarpa* become smaller as you ascend and, at about 300 feet, you gain a plateau so swept by the Antarctic gales that vegetation is reduced to compact, closely growing mosses, small *Uncinias*, and the conspicuous cushion-like masses of *Azorella selago*... Round the tops of the hills the wind has cut out wonderful terraces, from a few inches to a foot or two in height, with completely bare rock much disintegrated by the weather on top" (Hamilton 1894, p. 564).

As part of a detailed and thorough study of Macquarie Island flora and vegetation, Taylor (1955a) mapped the vegetation of the whole island at a scale of 1 inch to the mile (approximately 1:63 000), using four categories: feldmark, bare ground, wet tussock, subglacial herbfield. He described species and growth forms of plants in the plateau vegetation he called "Feldmark Formation", comprising the *Azorella selago* alliance with three associations and the *Dicranoweisia antarctica* alliance with one association. He noted the effects of wind on growth form and species composition, observing that "...increasing wind exposure successively favours the various associations, *Azorella selago, Azorella selago-Rhacomitrium crispulum, Rhacomitrium crispulum,* and *Dicranoweisia antarctica* in that order" (Taylor 1955a, p. 83).

Botanical nomenclature and spelling have changed since Taylor's (1955a) study. The species of *Azorella* on Macquarie Island is now recognised as the endemic *A. macquariensis* (Orchard 1989); *Dicranoweisia antarctica* is now *Hymenoloma antarcticum* (Ochyra & Broughton 2004); *Rhacomitrium* has become *Racomitrium.* Taylor's references to *Dicranoweisia antarctica* in fact referred to *Ditrichum strictum* (Ashton & Gill 1965).

Taylor (1955b) described in detail the structure and vegetation of two forms of feldmark terraces that he designated "windward" and "leeward". Ashton & Gill (1965) proposed an alternative to Taylor's vegetation classification, considering the feldmark as a complex *Azorella-Ditrichum* alliance, comprising a number of associations that occur on particular sites. They described the floristic simplification that occurs in response to increased wind exposure on both windward and leeward slopes, and considered the associations recognised by Taylor as convenient points of reference in a continuous gradation.

Utilising aerial photography and satellite imagery that was then available, Selkirk & Adamson (1998a, b) took a structural approach in producing a map of the vegetation and drainage patterns on Macquarie Island. They included within their category "open short herb vegetation", Taylor's (1955a) Feldmark Formation, Ashton & Gill's (1965) *Azorella-Ditrichum* alliance, and Adamson *et al.*'s (1993) sparse vegetation on unfavourable soils.

The considerable variability of vegetation on Macquarie Island in relation to environmental factors (aspect, altitude, wind exposure, soil type) has been noted by authors since Hamilton (1894) drew attention to the diminution in stature of plants with increase in altitude and the influence of the strong winds. This paper reports results from a 1980 survey which documents variation then apparent in species

composition in the open short herb, feldmark vegetation on the plateau of Macquarie Island (table 1).

METHODS

During January–March 1980, 16 line transects were studied at locations on the plateau of Macquarie Island: two sites on Windy Ridge, three sites to the north of Boot Hill, one site on the eastern lower slopes of Mt Law, two sites above the southwestern corner of the Green Gorge basin, two sites on the northern slopes of North Mountain, two sites on the western slopes of North Mountain, two sites on a ridge above the northern end of Sandy Bay, and two sites to the north of Prion Lake (fig. 1, pl. 1). As the study did not envisage revisiting the sites, precise locations of the transects were not recorded; map grid references were not noted and GPS technology was not then widely available.

Along a 20 m tape, fixed at each end, the species of first contact was recorded at 1 cm intervals (pl. 1A), hence there were 2000 species records per transect. From these data, percentage occurrences of species were calculated for each location (table 1). Identifications were made in the field with the aid of hand lenses. While most taxa could be identified to species level, some could only be determined to genus level and five (one species of moss, two species of liverwort and two species of lichen) were not able to be identified. Voucher specimens were not collected for later confirmation of identifications. At seven of the sites, observations of dead plants were recorded (tables 1, 2).

Although it is recognised that some taxonomic interpretations may change, the 1980 field identifications have been retained with names updated to accord with *Flora of Australia* (1993) for vascular plants, Seppelt (2004) and Ochyra & Broughton (2004) for mosses, McCarthy (2003) for liverworts, and Kantvilas & Seppelt (1992) for lichens.

RESULTS

The observations recorded in table 1 confirm the extremely variable nature of the open short herb, feldmark vegetation that has been described on the Macquarie Island plateau (Taylor 1955a, Ashton & Gill 1965, Selkirk & Seppelt 1984, Selkirk *et al.* 1990). Total vegetation occurrences ranged from 16.7% at the Boot Hill 3 site to 99.5% at the southwest Green Gorge 2 site. The three Boot Hill sites were in the area of serpentinite and harzburgite soils which support extremely sparse feldmark-type vegetation (Adamson *et al.* 1993, Selkirk & Adamson 1998a, b). The southwest Green Gorge sites were terraced, site 2 with continuous vegetation (Selkirk *et al.* 1988, Selkirk 1998) (pl. 1A). In total, 62 species were recorded of which 17 species were angiosperms, one was fern, 18 were mosses, 12 were liverworts and 14 were lichens. At least for the mosses the species total is an understatement as the species of *Andreaea* (of which seven are now known from the island, Seppelt 2004) could not be distinguished in the field.

The five species with occurrences at the largest number of sites, the angiosperms *Azorella macquariensis, Agrostis magellanica* and *Luzula crinita,* and the mosses *Racomitrium crispulum* and *Ditrichum strictum* were described as dominant, co-dominant or frequent by Taylor (1955a) in his Floristic List for the Feldmark Formation. All appear also in Ashton & Gill's (1965, p. 239) list of "species present in

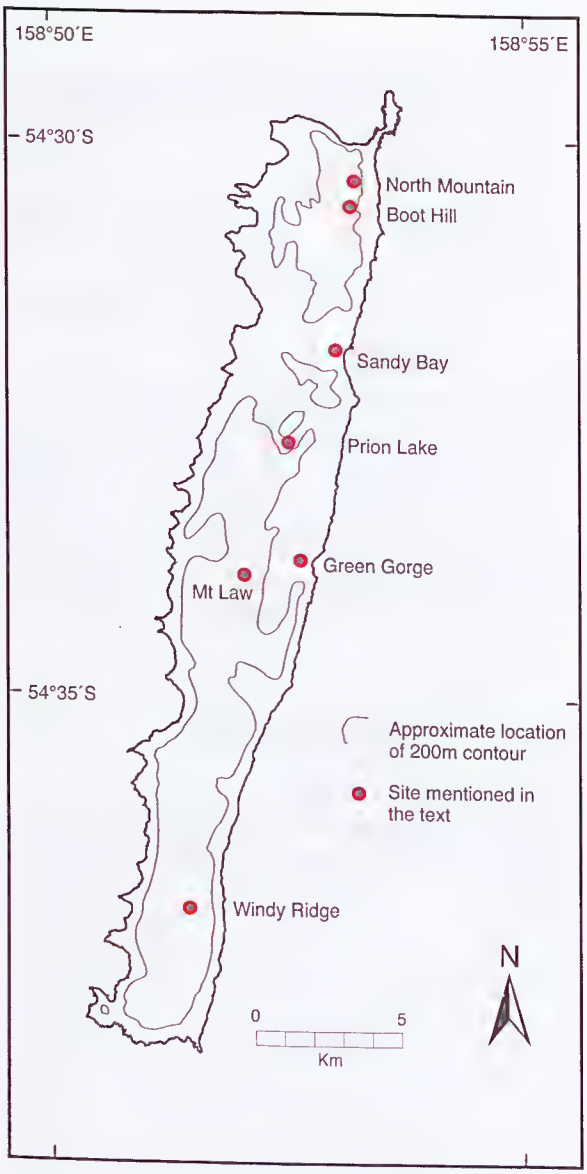

FIG. 1 — Map showing location of Macquarie Island and study sites.

Azorella-Rhacomitrium stripes, North Mountain".

In the present study (tables 1, 2), *A. macquariensis* occurred at 14 of the 16 sites; occurrences ranged from zero at the north Prion Lake sites to nearly 50% at the Mt Law site. In the transects from which dead *Azorella* was recorded, total *Azorella* occurrences were less than 10%; of this only 4% was dead at west North Mountain 2 while all was dead at Boot Hill 1.

Agrostis magellanica occurred at 14 of the 16 sites; occurrences ranged from zero at the Windy Ridge sites to 16.75% at the north North Mountain 1 site. In each of the seven transects from which dead plants were recorded, total *Agrostis* occurrences were less than 6%, and at only one, Sandy Bay Ridge 1, was there dead *Agrostis* (5.50% of total occurrences at the site).

Luzula crinita occurred at 14 of the 16 sites; occurrences ranged from zero at the Boot Hill sites to 10.22% at the Sandy Bay Ridge 2 site. In each of the seven transects from which dead plants were recorded, total *Luzula* occurrences were less than 6%, and at only one, the west North Mountain 1 site, was there dead *Luzula* (0.4% of total occurrences at the site).

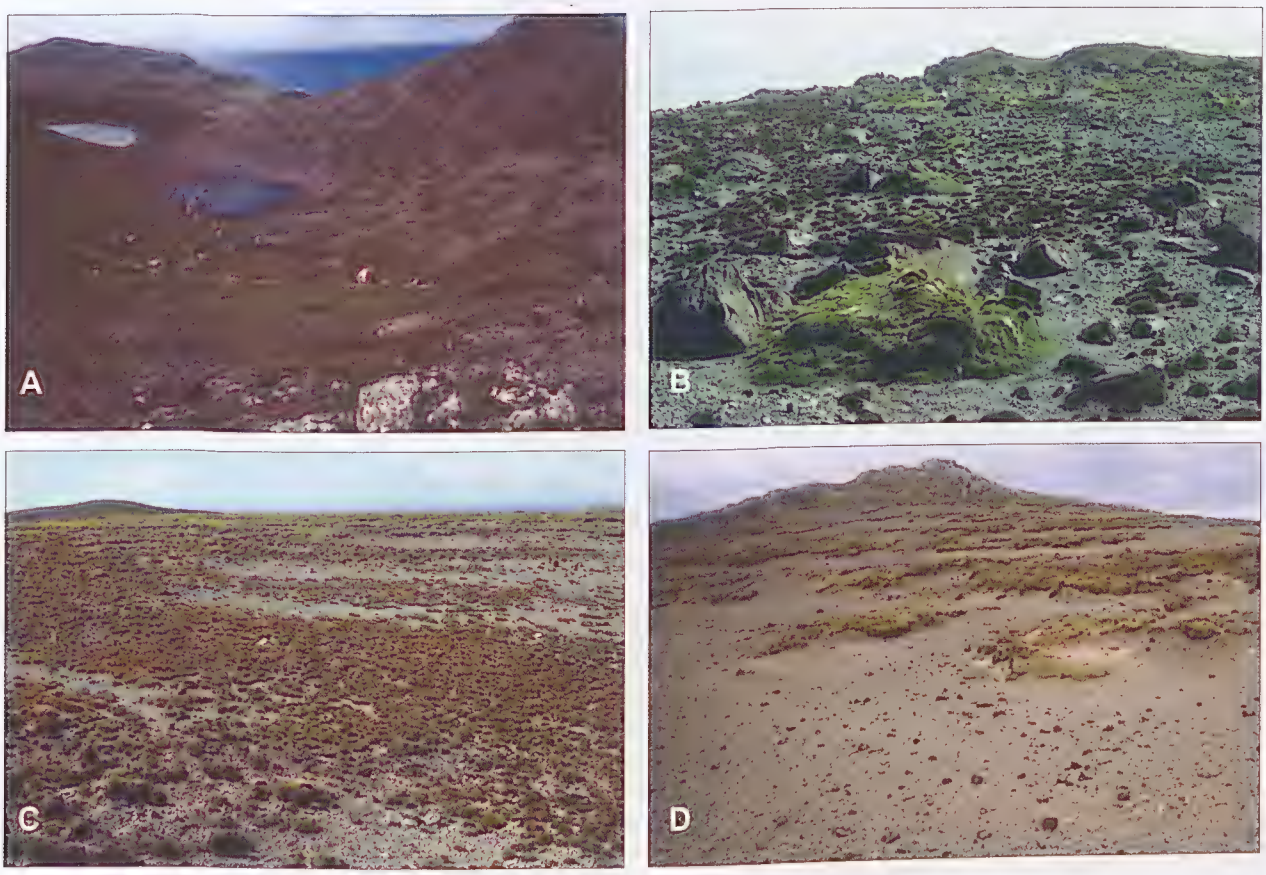

PLATE 1

(A) Transect study in progress at continuous vegetation site southwest of Green Gorge, February 1980. (B) Vegetation between Boot Hill and North Mountain, March 1980. (C) Vegetation to the north of Prion Lake, February 1980. (D) Vegetation on western slopes of North Mountain, February 1980.

Racomitrium crispulum occurred at each of the 16 sites; occurrences ranged from 0.05% at the Boot Hill 2 site to 20.45% at the Windy Ridge 1 site. At all seven transects from which dead plants were recorded, dead plants of *R. crispulum* were recorded, ranging from 3.26% of *R. crispulum* occurrences at west North Mountain 2 to 39.36% of *R. crispulum* occurrences at Windy Ridge 1.

Ditrichum strictum occurred at 12 of the 16 sites; occurrence ranged from zero at the Mt Law, southwest Green Gorge 1 and 2, and west North Mountain 2 sites to nearly 30% at the north Prion Lake 1 site. In the seven transects from which dead plants were recorded, total *D. strictum* occurrence was between 0 and nearly 30%; dead plants constituted between 0 and 23% of *D. strictum* occurrences (table 2).

DISCUSSION

Although the open short herb, feldmark vegetation on the plateau of Macquarie Island is floristically quite variable it is clear that *Azorella macquariensis* is an extremely important component. In December 2008 dieback was reported in *A. macquariensis* from the northern end of the plateau. By 2012 the dieback was regarded as extensive and severe throughout its range, with the most advanced areas of dieback almost devoid of live cushions (Threatened Species Section 2012).

Factors responsible for this "recent catastrophic decline" of *A. macquariensis* are currently unknown, but are under investigation (Threatened Species Section 2012 p. 3). Climate change has been suggested as an influence in the species' declining health (Threatened Species Section 2012). The 1980 transect data presented here well precede the first records of dieback in *A. macquariensis* on the plateau of Macquarie Island in December 2008. The data also precede the period of drier conditions (Whinam & Copson 2006) and dry soil conditions on the island (Threatened Species Section 2012), and were collected about halfway through the 50-year period of warming that has been noted in the second half of the twentieth century (Adamson *et al.* 1988, Tweedie & Bergstrom 2000, Pendlebury & Barnes-Keoghan 2007).

The transect data show that there were dead plants of 14 species recorded in 1980 (table 2); the cause of the deaths is unknown. In contrast to the present situation with *A. macquariensis*, the dead plants generally constituted only modest proportions of the vegetation at any given site. For instance, dead plants constituting 100% of the total occurrences of *A. macquariensis* at the Boot Hill 1 site actually represented only 0.6% of total plant occurrences at that site. Similarly, the high value of dead plants making up 50% of *Racomitrium pruinosum* occurrences at the Windy Ridge 1 site is at a location where this species makes up only 0.2% of total plant occurrences.

In a line intercept study of a 300-foot (91.44-m) transect downslope to the west on North Mountain, Ashton & Gill (1965) reported similarly modest percentages of dead plants: *A. macquariensis* constituted 15.8% of occurrences of which

TABLE 1

Plant species percentage occurrences along Macquarie Island feldmark transects in 1980. No entry means the species was not recorded at the site. Figures show occurrences of that species as a percentage of 2000 points of first contact along 20-metre line transects. For sites marked /d occurrences of dead plants are shown in format z/y; z is total percentage of points touching living or dead plants of that species, y is percentage of points touching dead plants of that species.

Species	Windy Ridge 1/d	Windy Ridge 2/d	Boot Hill 1/d	Boot Hill 2	Boot Hill 3	Mt Law	SW GG Terraces 1
VASCULAR PLANTS							
Acaena minor (Hook.f.) Allan						0.40	0.05
Agrostis magellanica Lam.			0.85	1.00	0.10	1.55	0.90
Azorella macquariensis Orchard	7.65/0.84	7.85/1.20	0.60/0.60	9.40	6.35	49.85	14.00
Cardamine corymbosa Hook.f.							
Colobanthus apetalus (Labill.) Druce				0.10			
Coprosma perpusilla Colenso							
Epilobium pedunculare A.Cunn.							
Epilobium brunnescens (Cockayne) P.H.Raven & Engelhorn							0.05
Festuca contracta Kirk	0.10	0.80/0.10				2.05	0.20
Grammitis poeppigiana (Mett.) Pic.-Serm.	0.30	0.25	0.70			0.75	1.30
Luzula crinita Hook.f.						10.40	
Montia fontana L.							
Pleurophyllum hookeri Buchan.			0.05	0.05			
Poa annua L.					0.05		0.05
Ranunculus crassipes Hook.f.							
Stellaria parviflora Banks & Sol. ex Hook.f.							
Stilbocarpa polaris (Hombr. & Jacquinot ex Hook.f.) A.Gray							0.25
Uncinia hookeri Boott							
MOSSES							
Andreaea spp.	21.30/4.75	25.05/4.85					0.30
Bartramia ithyphylla Brid.				0.10			
Breutelia pendula (Smith) Mitt.							
Conostomum pentastichum (Brid.) Lindb.	0.30	0.40			0.05		
Dicranoloma billardierei (Brid.) Paris	0.45	0.15				0.15	0.40
Ditrichum punctulatum Mitten							0.25
Ditrichum strictum (Hook.f. & Wilson) Hampe	11.30/1.25	17.50/3.95	25.40/4.50	10.85	9.75		
Hymenoloma antarcticum (Hook.f. & Wilson.) Ochyra	0.10						
Hypnum cupressiforme Hedw.						0.05	
Leptostomum inclinans R.Br. bis.				0.20		0.05	0.10
moss 1							

SW GG cont Veg 2	N North Mt 1	N North Mt 2	W North Mt 1/d	W North Mt 2/d	Sandy Bay Ridge 1/d	Sandy Bay Ridge 2	N Prion Lake 1/d	N Prion Lake 2
3.70	1.75	2.55	1.65/0.20		0.45	1.25	0.15	
9.05	16.75	15.75	2.70	5.25	2.70/0.15	9.20	0.90	0.30
41.33	9.50	6.05	8.20/1.75	5.80/0.25	0.35/0.05	0.45		
	0.05	0.10	0.10		0.35	0.40		
			0.20		0.05	0.15		
0.05								
0.45			0.35			0.55		
0.10	0.70	0.35			0.05	1.85		
	2.15	1.15	0.10					
0.20	0.85	0.60		0.05				
9.55	6.00	7.90	3.30/0.40	1.25	5.25	10.20	0.25	0.15
						0.25		
0.50	7.20	9.05		0.15				
						0.10		
2.65	0.40	0.50						
						0.25		
0.05								
1.55	0.65	0.50						
	1.10	0.60	0.15	0.25	1.15	0.55	0.35	2.95
0.05								
4.70	0.40	0.20			0.10	0.05		
			0.05		0.15		0.20	
3.40	0.75	0.20		0.05		0.25	0.05	
0.25	0.45				0.10	0.10		
	0.80	1.85	0.90		3.40	3.15	29.85/3.75	3.60
2.60								
0.10	0.05							
							0.20	

Table 1 cont.

Species	Windy Ridge 1/d	Windy Ridge 2/d	Boot Hill 1/d	Boot Hill 2	Boot Hill 3	Mt Law	SW GG Terraces 1
Notoligotrichum australe (Hook.f. & Wilson) G.L.Sm.	3.85/0.50	4.70/0.85				0.70	
Polytrichastrum alpinum (Hedw.) G.L.Sm.						0.20	0.70
Ptychomnion densifolium (Brid.) A.Jaeger							
Racomitrium crispulum (Hook.f. & Wilson) Hook.f. & Wilson	20.45/8.05	15.30/3.60	0.45/0.05	0.05	0.30	12.90	9.45
Racomitrium pruinosum (Wilson) Müll.Hal.	0.2/0.1	0.05					0.15
Rhacocarpus purpurascens (Brid.) Paris	2.00	1.15				0.05	0.25
Sanionia uncinata (Hedw.) Loeske							
Thuidiopsis furfurosa (Hook.f. & Wilson) M.Fleisch.							
LIVERWORTS							
Chiloscyphus bispinosus (Hook.f. & Taylor) J.J.Engel & R.M.Schust.				0.45		1.00	0.40
Cryptochila sp.						8.25	1.05
hepatic 1	1.05/0.10	0.15				0.10	0.05
hepatic 2							
Jamesoniella colorata (Lehm.) Spruce ex Schiffn.	5.80/1.65	4.20/0.20		0.70			
Lepidolaena sp.						0.15	
Lepidozia sp.	1.60	0.35					
Metzgeria sp.							
Plagiochila retrospectans Nees						0.05	
Riccardia aequicellularis (Steph.) Hewson				0.45	0.10		
Riccardia cochleata (Hook.f. & Taylor) Kuntze							
Riccardia sp.							
LICHENS							
Buellia sp. [grey]				0.10			0.60
Cetraria sp.	0.10						
Cladia aggregata (Sw.) Nyl.	0.60	0.55				1.00	0.20
Cladonia sp.							
Hypogymnia sp.	0.80	0.25				0.10	
lichen 1 [grey]							
lichen 2 [white + red]							
Peltigera sp.							
Pertusaria sp.	5.85	5.00				0.20	
Pseudocyphellaria glabra (J.D.Hook. and Taylor) Dodge							
Stereocaulon sp.							
Stereocaulon argus J.D. Hook. and Taylor	0.40	1.80				0.10	
Stereocaulon ramulosum (Sw.) Räuschel							0.20
Usnea sp.						0.20	
soil						9.55	
stones	15.80	14.50	71.95	76.55	83.30	0.20	69.10
TOTAL VEG	84.20/17.34	85.50/14.75	28.05/5.15	23.45	16.70	90.25	30.90

SW GG cont Veg 2	N North Mt 1	N North Mt 2	W North Mt 1/d	W North Mt 2/d	Sandy BBay Ridge 1/d	Sandy Bay Ridge 2	N Prion Lake 1/d	N Prion Lake 2
					2.65/0.25	1.25	0.75	
10.25	1.80	2.25	2.50/0.30	0.90	0.70	1.75		
0.15								
2.55	7.75	7.95	14.35/2.00	9.20/0.30	17.00/1.20	17.55	2.25/0.60	0.25
	0.10		0.05	0.05	0.15	0.65	0.10	
0.60	0.65	0.10						
	2.05	3.00						
0.35	0.05	0.05						
0.70	0.05	0.75				0.50	0.45	0.05
3.05			1.30/0.05	1.00/0.10				
0.65	0.15							
			0.05				0.25	
	1.45	1.00			1.40	2.70	4.00/0.15	0.40
	0.05		0.05	0.05				
			0.05					
0.10	0.05	0.15						
0.05								
							0.80	0.15
		2.00	0.30	0.40	0.50	0.10	0.20	2.25
0.60			1.10	0.25	0.10	0.20	0.05	
0.20		0.05				0.05		
0.05				0.10		0.15		
					0.45			
					0.10			
						0.10		
		0.30			0.25			
			0.15					
				0.15	0.90			
						0.15		
	0.10		0.10				0.10	0.45
	0.15	0.05			0.25	0.15		
0.05	36.05	35.00	62.30	75.10	61.45	45.95	59.10	89.45
99.95	63.95	65.00	37.70/4.70	24.90/0.65	38.55/1.65	53.05	40.90/4.50	10.55

TABLE 2

Percentage occurrences of dead plants along Macquarie Island feldmark transects in 1980. Figures show occurrences of dead plants as a percentage of that species' occurrences at the site. 0.00% means that live plants but no dead plants of that species were recorded at the site. No entry means the species was not recorded at the site.

Species	Windy Ridge 1/d	Windy Ridge 2/d	Boot Hill 1/d	W North Mt 1/d	W North Mt 2/d	Sandy Bay Ridge 1/d	N Prion Lake 1/d
VASCULAR PLANTS							
Acaena minor				12.12		0.00	0.00
Agrostis magellanica			0.00	0.00	0.00	5.50	0.00
Azorella macquariensis	10.98	15.29	100.00	21.34	4.30	14.29	
Grammitis poeppigiana	0.00	12.50			0.00		
Luzula crinita	0.00	0.00	0.00	12.12	0.00	0.00	0.00
MOSSES							
Andreaea spp.	22.30	19.36		0.00	0.00	0.00	0.00
Ditrichum strictum	11.06	22.64	17.72	0.00		0.00	12.56
Notoligotrichum australe	12.99	18.09				9.43	0.00
Polytrichastrum alpinum				12.00	0.00	0.00	
Racomitrium crispulum	39.36	23.52	11.11	13.94	3.26	7.06	26.67
Racomitrium pruinosum	50.00	0.00		0.00	0.00	0.00	0.00
LIVERWORTS							
Cryptochila sp.				3.85	10.00		
hepatic 1	9.52	0.00					
Jamesoniella colorata	28.45	4.76				0.00	3.75
Total dead plants as % of total vegetation at site	20.57	17.26	18.36	12.47	2.61	4.28	11.06

11.4% were dead and *R. crispulum* constituted 21.9% of occurrences of which 7.8% were dead.

In Taylor's (1955a) tables of floristic lists 23 species of vascular plants, 11 species of mosses, liverworts as a group and lichens as a group were assigned to the categories "dominant, co-dominant, abundant, frequent, common, occasional, rare, very rare". Ashton & Gill (1965) list seven species of vascular plants, 11 species of mosses, four species of liverworts and 10 species of lichens from feldmark stripes on North Mountain. They also provided numerical data for percentage occurrences of seven species of vascular plants, four species of mosses, liverworts and other mosses as a group, and lichens as a group along 300 feet (91.44 m) of line transect on which total vegetation occurrence was 42.7%. The 1980 transect numerical data presented above provide information about a greater number of species than earlier studies. In combination with Taylor's categories and descriptions, and Ashton & Gill's descriptions, these 1980 data provide a picture of the pre-dieback composition of Macquarie Island plateau open short herb, feldmark vegetation. Against this picture future developments in the Macquarie Island plateau vegetation can be evaluated, in fulfilment of the recommendation to "monitor the impact on *A. macquariensis* over time and associated changes in the feldmark ecosystem" in the Listing Statement for *A. macquariensis* (Threatened Species Section 2012, p. 5).

Through such future monitoring answers will emerge to many questions of interest concerning future vegetation on Macquarie Island's plateau, including whether the same species will recolonise areas affected by *A. macquariensis* dieback (from the soil seed bank, or from living plants remaining in the few isolated unaffected areas on the island) when and if present environmental perturbations stabilise; whether a subset of the previous vegetation will expand and form a different floristic mix; whether species now present elsewhere on the island will extend their ranges on the plateau; and whether species not presently on the island, i.e., alien species, will become established on the plateau. It is fervently to be hoped that present and future research management strategies and recovery plan (Threatened Species Section 2012) will be successful in conserving *A. macquariensis* so that this species will continue to have a role in the interesting, rare plateau vegetation of Macquarie Island.

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REFERENCES

Adamson, D.A., Selkirk, J.M. & Seppelt, R.D. 1993: Serpentinite, harzburgite and vegetation on subantarctic Macquarie Island. *Arctic and Alpine Research* **25**(3): 216–219.

Adamson, D.A., Whetton, P. & Selkirk, P.M. 1988: Warming on Macquarie Island: temperature changes reflecting Southern Hemisphere circulation and the Southern Oscillation. *Papers and Proceedings of the Royal Society of Tasmania* **122**: 107–112.

Ashton, D.H. & Gill, A.M. 1965: Pattern and process in a Macquarie Island feldmark. *Proceedings of the Royal Society of Victoria* **NS79**: 235–245.

Bureau of Meteorology 2012: *Climate statistics for Australian locations, summary statistics for Macquarie Island,* http://www.bom.gov.au/climate/averages/tables/cw_300004.shtml (accessed 29 August 2012).

Carmichael, N. 2007: Macquarie Island, its nature and conservation. *Papers and Proceedings of the Royal Society of Tasmania* **141**(1): 11–17.

Clements, M.A. & Jones, D.L. 2007: A new species of *Nematoceras* and characterization of *N. dienemum* (Orchidaceae), both from subantarctic Macquarie Island. *Telopea* **11**(4): 405–411.

Flora of Australia 1993: Volume 50, Oceanic Islands 2, Canberra: Australian Government Publishing Service: 606 pp.

Hamilton, A. 1894: Article LXV Notes on a visit to Macquarie Island. *Transactions of the New Zealand Institute* **27**: 559–579.

Kantvilas, G. & Seppelt, R.D. 1992: The Lichen flora of Macquarie Island: introduction and an annotated checklist of species. *ANARE Research Notes* **87**: 1–20.

McCarthy, P.M. 2003: *Catalogue of Australian Liverworts and Hornworts.* Canberra: Australian Biological Resources Study: 137 pp.

Ochyra, R. & Broughton, D.A. 2004: New moss records from the Falkland Islands. *Journal of Bryology* **26**(3): 226–230.

Ochyra, R., Bednarek-Ochyra, H. & Seppelt, R.D. 2008: *Philonotis polymorpha* (Müll.Hal.) Broth. *In* Blockeel, T.L. (ed.): New national and regional bryophyte records. *Journal of Bryology* **30**(2): 3–9.

Orchard, A.E. 1989: *Azorella* Lamarck (Hydrocotylaceae) on Heard and Macquarie Islands. *Muelleria* **7**(1): 15–20.

Pendlebury, S.F. & Barnes-Keoghan, I.P. 2007: Climate and climate change in the sub-Antarctic. *Papers and Proceedings of the Royal Society of Tasmania* **141**(1): 67–81.

Selkirk, J.M. 1998: Active vegetation-banked terraces on Macquarie Island. *Zeitschrift für Geomorphologie N.F.* **42**(4): 483–496.

Selkirk, P.M. 2007: The nature and importance of the sub-Antarctic. *Papers and Proceedings of the Royal Society of Tasmania* **141**(1):1–6.

Selkirk, P.M. 2009: Fifth Phillip Law Lecture: Macquarie Island, Jewel in the Southern Ocean, Hobart 17 June 2006. *In*: *The Phillip Law Lectures, Volume 2: 2006-2008.* Department of Economic Development and Tourism, Tasmania: 8–24.

Selkirk, P.M. & Adamson, D.A. 1998a: *Structural vegetation and drainage of Macquarie Island, map, 1:25 000.* Published by Australian Antarctic Division, Hobart (edition 2, 2001), http://gcmd.nasa.gov/KeywordSearch/Metadata.do?Portal=amd_au&MetadataView=Full&MetadataType=0&KeywordPath=&OrigMetadataNode=AADC&EntryId=MIvegmap.

Selkirk, P.M. & Adamson, D.A. 1998b: Map of structural vegetation types and drainage on subantarctic Macquarie Island: Details about the compilation and interpretation of the map, http://data.aad.gov.au/metadata/other_data/macca_veg_map_doco.html.

Selkirk, P.M. & Seppelt, R.D. 1984: Fellfield on Macquarie Island. *Tasmanian Naturalist* **78**: 24–26.

Selkirk, P.M., Adamson, D.A. & Seppelt, R.D. 1988: Terrace types and vegetation dynamics on Macquarie Island. *Papers and Proceedings of the Royal Society of Tasmania.* **122**(1): 59–64.

Selkirk, P.M., Seppelt, R.D. & Selkirk, D.R. 1990: *Subantarctic Macquarie Island Environment and Biology.* Cambridge University Press, Cambridge: 285 pp.

Seppelt, R.D. 2004: *The Moss Flora of Macquarie Island.* Australian Antarctic Division, Kingston, Tasmania, Australia: 328 pp.

Taylor, B.W. 1955a: *The Flora, Vegetation and Soils of Macquarie Island.* ANARE Reports Series B, Volume **11** Botany: 192 pp.

Taylor, B.W. 1955b: Terrace formation on Macquarie Island. *Journal of Ecology* **43**: 133–137.

Threatened Species Section 2012. *Listing Statement for* Azorella macquariensis *(Macquarie cushions).* Department of Primary Industries, Parks, Water and Environment, Tasmania.

Tweedie, C.E. & Bergstrom, D.M. 2000: A climate change scenario for surface air temperature at Subantarctic Macquarie Island. *In*: Davison, W., Howard-Williams, C., & Broady, P. (eds): *Antarctic Ecosystems: Models for Wider Understanding.* New Zealand Natural Sciences, Christchurch: 272–281.

Whinam, J. & Copson, G. 2006: *Sphagnum* moss: an indicator of climate change in the sub-Antarctic. *Polar Record* **42**(220): 43–49.

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Brief Communication

THE SUB-ANTARCTIC AS A SOURCE OF HUMAN ENRICHMENT — THE CASE OF SOUTH GEORGIA

by Bjørn L. Basberg

(with three text-figures and four plates)

Basberg, B.L. 2012 (14:xii) The sub-Antarctic as a source of human enrichment — the case of South Georgia. *Papers and Proceedings of the Royal Society of Tasmania* 146: 81–88. ISSN 0080-4703. Norwegian School of Economics (NHH), 5045 Bergen, Norway. Email: Bjorn.Basberg@nhh.no

South Georgia and how its history and heritage may be considered a unique source of human enrichment today is considered in the light of the sealing and whaling eras and more recent times when science and tourism dominate. Attitudes to the whaling heritage have gradually changed in this latter period. The spectacular natural heritage is emphasised, and a recent project on habitat restoration at the island is mentioned.

Key Words: South Georgia, industrial heritage, natural heritage, whaling, habitat restoration.

INTRODUCTION

Among the sub-Antarctic islands, South Georgia stands out as the second largest (after Îles Kerguelen), and the one with historically the most extensive human activity. The industrialised whaling area that lasted from 1904 to 1964, in particular, is unique. The industry was a source of income and "enrichment" in a very literal sense, but was also — in retrospect — a very controversial industry. So, the history of the industry has been problematic, and only gradually has it become more common to consider it as a valuable heritage and a source of human enrichment.

The aim of this paper is to review the development of the whaling industry, but particularly to focus on the post-whaling era and how attitudes to the physical and other remains of the industry on the island have gradually changed. After years of decline and neglect, the remains of the whaling stations have been surveyed, some environmental clean-up has taken place, a museum has been created and selected buildings restored. In 2005 the South Georgia Heritage Trust (SGHT) was established.

South Georgia's history is, of course, more than whaling. Exploration and science have always been an integral part of the history that today has become heritage. Ernest Shackleton's association with the island is arguably the most well-known part of this heritage (Burton & Venables 2001). Then there is the nature, wildlife and the *natural* heritage. South Georgia is an important habitat for birds, penguins and seals — in fact it is the largest breeding ground for some species (Poncet & Crosbie 2005, Burton & Croxall 2012). This natural heritage is obviously a decisive source of human enrichment for today's visitors. However, invasive species are threatening some of this wildlife, and a challenging project on habitat restoration has been initiated by the SGHT. This will be covered briefly here, with a focus on how the unique "mix" of natural and cultural heritage that is so evident at South Georgia could be conceived of as a source of human enrichment.

THE WHALING ERA

The main sub-Antarctic industry of the nineteenth century was sealing, dominated by American and British sealers who discovered new islands and grounds where stocks of fur seals (*Arctocephalus* sp.) and Elephant Seals (*Mirounga leonina* (Linnaeus, 1758)) were exploited. South Georgia probably was visited by sealers in 1786 and the activity there peaked during the first two decades of the nineteenth century. The sealers then moved to the South Shetland Islands and elsewhere (Headland 2009).

Whaling around several sub-Antarctic islands was also taking place throughout the nineteenth century — mainly by New England whale ships associated with what may be called "the American Century of Whaling". However, these whalers were mostly harvesting whaling grounds further north, along the Australian coast and further north in the Pacific, Indian and Atlantic oceans (Dolin 2007).

The twentieth-century "Modern whaling" in Antarctic waters started in Grytviken, South Georgia, in 1904 (pl. 1). It very soon led to the establishment of more shore whaling stations at South Georgia (six before World War I) and elsewhere in the sub-Antarctic (Tønnessen & Johnsen 1982, Headland 1984, Hart 2001).

Around 1920 — the heyday of shore station whaling in the Antarctic region — there were stations operating at four islands (fig. 1): South Georgia (six): Grytviken, Husvik, Stromness, Leith Harbour, Prince Olav Harbour, Ocean (in addition Godthul — a floating factory anchorage and base); Deception Island (South Shetlands) (one); South Orkney Islands (one); and Kerguelen (one).

At the same time, floating factory ships were whaling in the South Shetlands in large numbers. So, before 1925, South Georgia and the South Shetlands were the main whaling areas. Very little went on elsewhere. The establishments at Kerguelen and the South Orkney Islands were short-lived and never fully developed industrially and technologically.

PLATE 1
The Grytviken whaling station at South Georgia around 1920. Source: Com. Chr. Christensen's Whaling Museum.

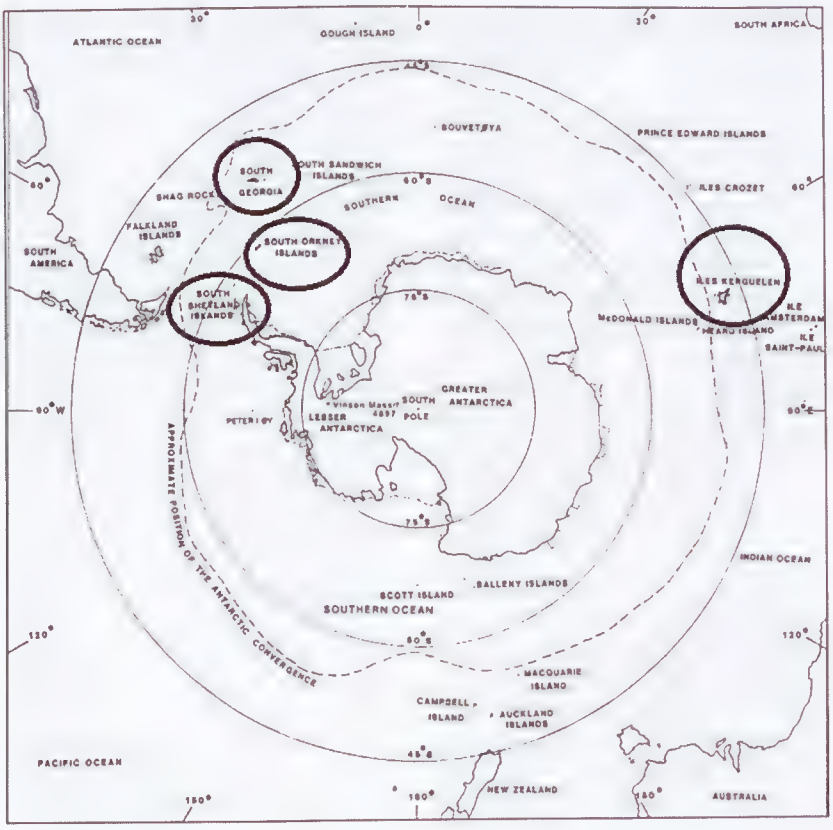

FIG. 1 —Location of former whaling shore stations in the Antarctic region.

An important new phase in the development of the whaling industry was started by C.A. Larsen — the pioneer in Grytviken — when he took a factory ship and catcher boats into the Ross Sea in 1923, operating independently of shore bases. From then on Antarctic whaling took a new direction, technologically as well as geographically.

In 1925 the so-called stern hauling up slip was invented and adopted on a Norwegian floating factory ship. Its use soon became widespread. Whaling expanded in the late 1920s, and operated independently of islands, territorial waters, licences and leases. This so-called "pelagic whaling" hunted for whales throughout the Southern Ocean around the Antarctic continent, and followed the ice as it retreated during the Austral summer (Tønnessen & Johnsen 1982).

The sub-Antarctic shore stations gradually lost their importance and several plants were permanently shut down during the economic crises (which also hit whaling) in the early 1930s. Only at South Georgia was some activity resumed, and three stations continued operations into the early 1960s: the Scottish Salvesen at Leith; the Argentine Comp. Argentina de Pesca at Grytviken; and the Nowegian Tønsberg Hvalfangeri at Husvik.

The Salvesen Company also used South Georgia (Leith and Stromness) as a repair base for their pelagic expeditions, thus the island to some extent was also important for this aspect of the industry. However, the pelagic expeditions typically maintained and laid up their fleets between seasons at locations further north (Cape Town, Montevideo, Hobart, Stewart Island (Kaipipi Shipyard) and Norway).

In terms of economic or commercial importance, whaling was by far the most important industry ever to have taken place in the Antarctic region. Sealing before and fisheries afterwards, cannot compare. Whaling in this period in a very literal sense was a decisive source of human enrichment.

POST-WHALING DECLINE AND SURVEYS

What has happened to the whaling sites since the industry closed down? And to what extend can this phase in the history also be a source of human enrichment? This is potentially a challenging concept given the derelict state of most of the sites today (pl. 2). Prince Olav Harbour, for example, was already abandoned in 1931, so its post-whaling history (80 years) is now much longer than its actual whaling history which lasted only about 14 years. However, even the stations that were closed down in the 1960s are in a severe state of decline — after being abandoned for about 50 years.

The post-whaling history of these sites has evolved through stages. For some years the stations were maintained. When a possible resumption of whaling was abandoned, caretakers left, and the stations went into a period of neglect and decline. The harsh climate of South Georgia was in itself responsible for the decline, but throughout the 1970s frequent visiting fishing vessels in particular contributed to the process, and stations were also severely looted. During this period, there was a time when the economic potential of recovering scrap metal from the stations was considered, but this has come to nothing. Instead some clean up of the stations was motivated by environmental concerns. This included removal of oil, asbestos and debris. Over the past 20 years or so, the remains of whaling activities have also increasingly been considered as industrial heritage (Basberg 2004).

These stages are to some extent connected or associated with shifts in ownership of, and thus formal responsibility for, the stations. For some years the stations remained under the ownership of the original whaling companies from Norway, Argentina and Britain. In 1975 they were all taken over by the Scottish company Salvesen which had

PLATE 2
The whaling station Prince Olav Harbour in decay. Photo: Author

FIG. 2 — Grytviken whaling station – site plan. Source: NARE 92/93.

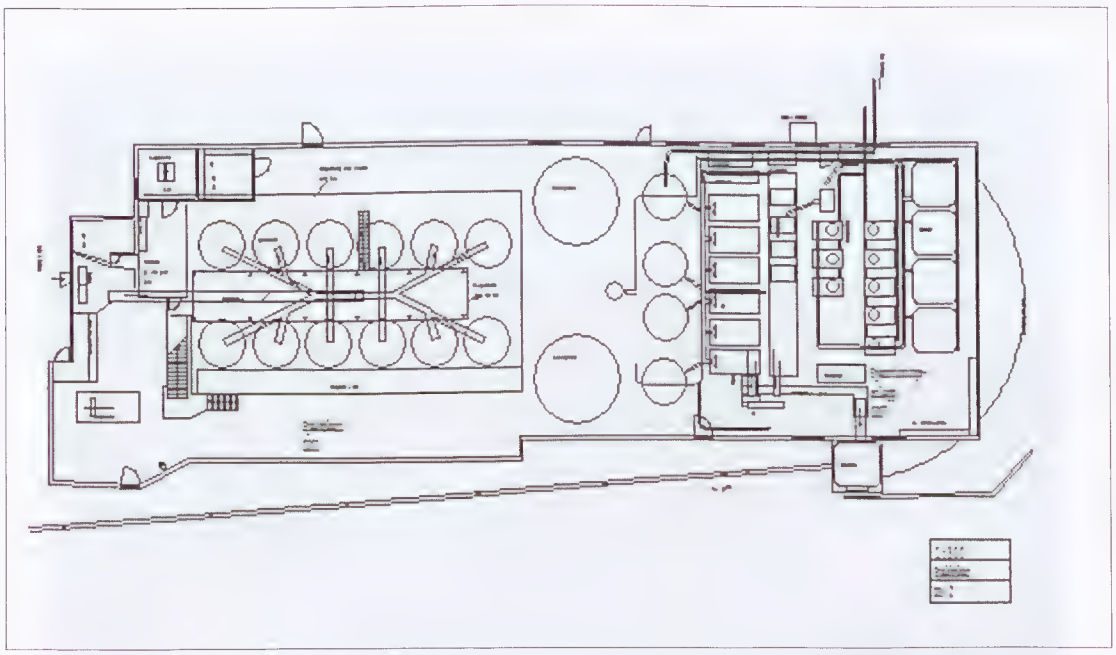

FIG. 3 — An example of a building plan; Leith Harbour blubber cookery: Source: NARE 96/97.

been operating Leith Harbour, Stromness and Prince Olav Harbour. In 1991 Salvesen transferred ownership to the Government of South Georgia and the South Sandwich Islands (GSGSSI), which has been responsible for the management of the sites since then.

When awareness of the derelict state of the stations grew during the 1980s, the question arose of whether it might be possible to survey them before the structures completely collapsed. To some extent it was too late, but throughout the 1990s funding became available from the Norwegian Antarctic Research programs (NARE) for three extensive surveys of the remains of the whaling stations. The project was called "South Georgia Industrial Archaeological Project". Fieldwork lasted from four weeks to more than two months, and the sites were recorded in detail by teams with backgrounds in industrial archaeology, economic history, ethnology and architecture — some with experience specifically from related work at Spitsbergen.

After a halt, the surveys were continued in 2009 in Prince Olav Harbour and Ocean Harbour as part of the so-called LASHIPA project (Large Scale Historical Exploitation of Polar Areas). This was a project within the International Polar Year with funding from the Dutch and Swedish research councils. LASHIPA conducted fieldwork both in the Arctic and the Antarctic, and two fieldtrips/surveys took place at South Georgia and other sub-Antarctic islands. And it brought to a conclusion the South Georgia whaling station surveys about 20 years after the idea was born.

So what was accomplished? All the sites were surveyed and revised station maps were made (Basberg 2004, Avango *et al.* 2011). Systematic photo documentation both of exteriors and interiors was undertaken. This included every single room as far as they could be located. But even in severely collapsed structures this was often possible, and about 2000 rooms were identified and surveyed. Every individual structure or building was also measured and plan drawings of some 400 structures were made.

Revised functional station maps were constructed (fig. 2). The various buildings were grouped in categories according to their function: production, workshops, accommodation, stores etc. indicating that these stations were really small industrial communities, housing about 300 men on a seasonal basis.

Another category of maps was made up of building plans consisting of the interior layout of every physical structure (fig. 3). This part of the work contributed new knowledge to our understanding of these stations. From archives, photographs and other sources on these sites much is known about how the stations operated and what they looked like. But details about how they looked *inside* — especially the accommodation quarters — were less known. Possibly the most important outcome of this research was a much more detailed understanding of the whalers' living and working conditions.

FROM SCRAP TO INDUSTRIAL HERITAGE

What was the purpose of these extensive surveys? When the project was conceptualised in the late 1980s there were no plans for physical preservation and restoration. The sites were gradually collapsing, and it was believed that detailed surveys could be one way of at least preserving the knowledge about this industry, and also be a source of information for further historical research on the whaling industry at South Georgia.

This proved to some extent to be a valid justification, but the 1990s also marked a turning point in the attitude towards the former whaling stations which can be captured in the phrase "from scrap to industrial heritage".

In 1990 the South Georgia Museum was founded — located in the former Manager's Villa in Grytviken. The intention of its founder, Nigel Bonner, was to create a whaling museum and the museum was originally and for many years called the South Georgia Whaling Museum. But the focus was gradually broadened and it now displays most aspects of South Georgia history and heritage. Visitors are mainly cruise ship passengers. The annual numbers reached about 8000 during the peak seasons before 2009 (South Georgia Museum, Annual Reports).

An indication of the increased interest in South Georgia's past was the foundation of Øyas Venner (Friends of the Island) in 1997. This is an association for former South Georgia whalers based in Norway. The South Georgia Association, founded in 2001, is comprised mainly of former scientists and servicemen who had worked there. Such associations show how past experience is still a source of human enrichment for those involved. Both associations are also involved in projects at the island, and Øyas Venner has in particular focused its interest on the Whaler's Church in Grytviken and the graveyards around the island.

The South Georgia Museum was created by a private initiative, but was very much supported (and paid for) by the GSGSSI. The GSGSSI's active role at this time was evident: in 1990 an initial environmental clean up operation was undertaken, primarily focusing on removing oil from various tanks. This was continued in Grytviken in a very extensive operation in 2003 that involved three main tasks. The first task was the removal of the remaining oil from tanks. The second task was removal of asbestos which had been used extensively, mainly for insulation of tanks and pipes in the stations. It became a major concern for the government and the main justification for the project (Pasteur & Walton 2006). The third task was to dismantle a number of buildings to make the site safe for visitors. The main installations, equipment and machinery were left *in situ*, so that Grytviken now appears as an "Open Air Museum" (pl. 3). However, the clean up obviously altered Grytviken, and some advisers suggested a much more careful approach which included paying more attention to preserving buildings (Morrison 2011). On the other hand, four other former whaling stations are still complete ruins and left to decay naturally. Grytviken is the only station that is freely accessible for visitors and interpretation signs have been provided. The former whaling and sealing vessels that for years were semi-sunk along jetties have also been stabilised and beached. Plans are being made for their restoration.

No buildings, other than the ones occupied by the museum, have so far been restored in Grytviken. Potential projects are being considered, for example the former whalers' accommodation barracks (*Nybrakka*) and the so-called Discovery House at King Edward Point where the Discovery Investigations for many years had its shore-based site. So far, only one building outside Grytviken has been restored: the Manager's Villa in Husvik Harbour. It has for many years been used as accommodation by visiting scientists. However, the house is not used at present due to the need for more asbestos clean-up, illustrating the heritage challenges at these sites. In summary, there may be several examples of important heritage at South Georgia that could be sources of "human enrichment" in a wide sense, but any

PLATE 3
Grytviken after the environmental clean-up. Photo: Author.

PLATE 4
The former Manager's Villa in Stromness where Ernest Shackleton and companions arrived in May 1916. Photo: D. Nævestad, NARE 89/90.

restoration is challenging and certainly involves substantial expenditure.

THE SHACKLETON LEGACY

Visitors to South Georgia are fascinated by the whaling heritage, but no doubt the historical "hero" of the island is Ernest Shackleton. He died there in 1922 and was buried there; his gravesite is a major attraction (Burton & Venables 2001). The museum exhibits his legacy. A replica of the lifeboat *James Caird* that took him from Elephant Island to South Georgia in May 1916 is now on display. The former Manager's Villa in Stromness where Shackleton and his companions arrived after the epic crossing of the island is still *in situ*. Repeating this crossing — in part or in full — has been popular for several years. The Shackleton story has also become a model for leadership. Thus, in several very different ways his legacy contributes to human enrichment today.

For many years the Manager's Villa in Stromness that was in use when the station closed down in the early 1960s, was also believed to be where Shackleton arrived and there were plans for a museum there and for restoration. Fortunately, before anything was done, it was verified that that house was not set up in Stromness until years after Shackleton's visit and the correct building (pl. 4) (i.e., the former Manager's Villa) was identified (Basberg & Burton 2006). Plans for a restoration of *this* building are being discussed, but nothing has so far been done because the building is almost beyond repair, and secondly, the house is in the centre of the Stromness site which, due to the asbestos there, is out of bounds for visitors. Except for Grytviken, there are 200-metre exclusion zones around all the stations. This means that if anything should be done in terms of restoration of this particular building, an expensive environmental clean-up operation will have to be completed. Again, costs are substantial and highlight some of the problems faced for heritage work at South Georgia.

NATURAL HERITAGE AND HABITAT RESTORATION

Antarctic tourists in general are primarily interested in wildlife and the scenery — penguins and ice. Such attitudes probably also apply to the sub-Antarctic tourists (Basberg 2010). South Georgia in particular has some spectacular wildlife which is a decisive part of the experience of modern visitors and a source of human enrichment. To preserve this natural heritage should be a priority, and has indeed been argued for by numerous visitors to the island. It has been forcefully advocated in books, some of which themselves are sources of human enrichment. One example is Pauline and Tim Carr's *Antarctic Oasis* where they conclude: "Above all else we wish that the name of South Georgia will forever represent an icy paradise, a place where nature is still mostly robust and the way of life of millions of birds, penguins, and seals goes on almost unaltered by the peripheral presence of humans" (Carr & Carr 1998, p. 254).

Preservation of the natural heritage requires management. The overall responsibility for the management of this part of the heritage lies with the GSGSSI. Another important institution at South Georgia is the British Antarctic Survey (BAS), which operates two research stations (King Edward Point and Bird Island) and for some decades has been undertaking research at the island of relevance to the natural heritage. South Georgia Heritage Trust (SGHT) has become a third important stakeholder, founded through an initiative of the government in 2005. It is a private trust, registered and managed in Dundee, Scotland.

The aims of the trust are twofold, namely to engage in projects (raise money and give grants) relating to both the natural and the historical heritage of the island. Among the historical heritage work, the trust is managing the South Georgia Museum and has so far restored one building (Husvik) and has plans for more. An oral history project has also been undertaken (www.sght.org).

Among natural heritage projects, the trust has sponsored several research projects and publications, but is now focusing on one very large project: the so-called Habitat Restoration Project. This project is about eradicating Brown Rats (*Rattus norvegicus* (Berkenhout, 1769)), which were introduced to the island by sealers and whalers over two centuries. It is a challenging project logistically as well as financially, and is justified by the fact that some of South Georgia's unique birdlife is threatened. Together with the removal of introduced Reindeer (*Rangifer tarandus* (Linnaeus, 1758)), a project in the planning by GSGSSI, it will take South Georgia closer to its original state.

A first phase of the Habitat Restoration Project was undertaken during the 2010/11 season. The trust is working with, among others, New Zealand experts, and uses the same methods (spreading bait from helicopters) that have been used at Campbell Island and Macquarie Island. However, South Georgia is a larger and topographically more complex island than Campbell and Macquarie islands, and after the first season when only about 10% of the rat-infested area is treated, it is already the largest project of its kind in history (www.sght.org/sght-habitat-restoration-project).

CONCLUSIONS

In the context of the topic of the sub-Antarctic as a source of human enrichment, it may be asked what role — what "function" — this and other similar islands may have. They obviously are and have been important in many ways. They have been sites for commercial activities, from the earlier exploitative industries of sealing and whaling, to today's fishing and tourism. They are also important sites for science and research.

In one way or another such functions relate to "human enrichment", although we may primarily associate this concept with the experiences of modern tourist visitors. Since these visitors appear to be mostly interested in the natural heritage, and some may see the whaling industry in a very negative way, a management or policy option today could be a complete removal of the former whaling stations so that the island really could be brought back to a pristine nature reserve. This is not the view taken here. Instead it is argued that South Georgia's uniqueness is very much about its *mixture of natural and historical heritage*. There are few places where a spectacular example of sub-Antarctic nature meets with a unique historical heritage. South Georgia is one such place.

The historical heritage is very much associated with exploitative industries. They were industries that we tend to disapprove of today. The heritage can nevertheless educate us about what went wrong — and therefore still be a source of human enrichment. So, the sources of human enrichment

at South Georgia in the future should — at least to some extent — be based on the heritage of these industries in combination with its unique nature and natural heritage.

POSTSCRIPT

Heritage work at South Georgia is continuing and being escalated. Assessments during the 2011/12 season have shown successful results for the first phase of SGHT's Habitat Restoration Project, and the project is planned to continue in 2013. GSGSSI is planning for a removal of introduced reindeer in the same period. Relating to the cultural heritage, in December 2011 the governments of Norway and the UK signed an agreement on polar research in which some projects (possible restoration of houses and vessels) are destined for South Georgia.

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REFERENCES

Avango, D., Basberg, B.L, Gustafsson, U. & Rossnes, G. 2011: *LASHIPA 6: Archaeological expedition on South Georgia 3 March–12 April 2009.* Arctic Center, University of Groningen, Groningen: 113 pp.

Basberg, B.L. 2004: *The Shore Whaling Stations at South Georgia. A Study in Antarctic Industrial Archaeology.* Novus Press, Oslo: 226 pp.

Basberg, B.L, 2010: Antarctic tourism and maritime heritage. *International Journal of Maritime History*, **22**, No. 2: 227–246.

Basberg, B.L. & Burton, R. 2006: New evidence on the Manager's Villa in Stromness Harbour, South Georgia. *Polar Record* 42: 147–151.

Burton, R. & Venables, S. 2001: *Shackleton at South Georgia.* Gemini Press, Towcester: 25 pp.

Burton, R. & Croxall, J. (eds) 2012: *A Fieldguide to the Wildlife of South Georgia.* South Georgia Heritage Trust/Princeton Wildguides, Basingstoke: 200 pp.

Carr, T. & Carr, P. 1998: *Antarctic Oasis. Under the Spell of South Georgia.* W.W. Norton & Co, London: 256 pp.

Dolin, E.J. 2007: *Leviathan. The History of Whaling in America.* W.W. Norton & Co, New York: 479 pp.

Hart, I. 2001: *Pesca. A History of the Pioneer Modern Whaling Company in the Antarctic.* Aidan Ellis Publishing, Whinfield: 548 pp.

Headland, R.K. 1984: *The Island of South Georgia.* Cambridge University Press, Cambridge: 293 pp.

Headland, R.K. 2009: *A Chronology of Antarctic Exploration.* New Quaritch Publ., London: 722 pp.

Morrison, M. 2011: *Inspection of the Disused Shore-based Whaling Stations.* Purcell Miller Tritton LLP, Norwich: 93 pp.

Pasteur, L. & Walton, D. (eds) 2006: *South Georgia: Plan for Progress. Managing the Environment 2006-2010.* British Antarctic Survey/Government of South Georgia and the South Sandwich Islands, Cambridge: 74 pp.

Poncet, S. & Crosbie, K. 2005: *A Visitor's Guide to South Georgia.* WildGuides Ltd, Aldermaston: 180 pp.

Tønnessen, J.N. & Johnsen, A.O. 1982: *The History of Modern Whaling.* C. Hurst & Co, London: 798 pp.

South Georgia Museum 2009–2011: *Annual Reports.*

South Georgia Heritage Trust (SGHT) 2012: www.sght.org (accessed August 2012).

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BRIEF COMMUNICATION

THE IMPACTS OF PAST CLIMATE CHANGE ON SUB-ANTARCTIC NEARSHORE ECOSYSTEMS

by Ceridwen I. Fraser

(with one text-figure and two plates)

Fraser, C.I. 2012 (14:xii): The impacts of past climate change on sub-Antarctic nearshore ecosystems. *Papers and Proceedings of the Royal Society of Tasmania* 146: 89–93. ISSN 0080-4703. Fenner School of Environment and Society, ANU College of Medicine, Biology & Environment, Australian National University, Canberra, ACT 0200, Australia. Email: ceridwen.fraser@gmail.com

Pleistocene glacial–interglacial cycles would have resulted in drastic changes in the structure of sub-Antarctic littoral ecosystems. Genetic data indicate that the large kelps that dominate intertidal and shallow subtidal sub-Antarctic shores today (such as *Macrocystis pyrifera* and *Durvillaea antarctica*) were extirpated from these high latitude regions by sea ice scour during glacial maxima. These macroalgae, and their associated faunal communities, were able to return to the sub-Antarctic islands during interglacial periods by drifting at sea in the path of the Antarctic Circumpolar Current. During glacial maxima, sub-Antarctic littoral communities would have been severely reduced, comprising mainly ice-scour hardy taxa such as small and/or seasonal macroalgae, and mobile molluscs.
Key Words: sub-Antarctic, ice scour, postglacial recolonisation, rafting, West Wind Drift, global warming.

INTRODUCTION

Earth's climate fluctuated between glacial and interglacial periods throughout the Quaternary (Petit *et al.* 1999). With each major climate shift, many organisms were forced to change their distributional ranges, generally moving towards the equator as the planet entered an ice age, and towards the poles during interglacial periods (e.g., Hewitt 2000, Fraser *et al.* 2012). Where organisms have recolonised higher-latitude regions post-glacially, these more recently established populations generally show lower genetic diversity than at lower latitudes, where populations have been able to persist locally or *in situ* for longer periods (Hewitt 2000).

Several recent studies on Southern Hemisphere sub-polar and cool-temperate littoral ecosystems have found such latitudinal genetic diversity gradients, indicating that many of the sub-Antarctic islands have been recolonised post-glacially (approximately during the last 18 000 years) by highly-dispersive marine species that are unable to withstand ice scour (Fraser *et al.* 2009, Nikula *et al.* 2010). In contrast, sub-Antarctic marine species that are less adversely affected by sea ice do not appear to show strong genetic diversity gradients. These biological studies support the hypothesis that Antarctic sea ice extended to most of the sub-Antarctic islands at the Last Glacial Maximum (LGM) (Fraser *et al.* 2009) (fig. 1). Furthermore, they suggest that the ecological structure of contemporary sub-Antarctic littoral ecosystems is relatively young, and has changed drastically throughout the glacial–interglacial cycles of the Quaternary.

SUB-ANTARCTIC LITTORAL ECOSYSTEMS TODAY

Many intertidal and shallow subtidal ecosystems of the sub-Antarctic islands north of the Antarctic Polar Front (APF) are dominated by Southern Bull-Kelp (*Durvillaea antarctica* (Chamisso) Hariot) communities (e.g., Klemm & Hallam 1988) (pl. 1). Southern Bull-Kelp can reach densities of more than 100 kg wet mass/m^2 (Haxen & Grindley 1985), and makes a large contribution to local marine (Kaehler *et al.* 2000) and terrestrial (Dufour 2011) trophic webs. Kelp plays an important role in local community structure by facilitating settlement and growth of some macroalgal species over others (Taylor & Schiel 2005), and providing habitat and food for a diverse array of invertebrate taxa (Edgar & Burton 2000, Smith & Simpson 2002) including polychaetes, echinoderms, crustaceans and molluscs. Beach-cast bull-kelp (wrack) is consumed by a wide variety of insects and crustaceans (Dufour 2011) which in turn form the prey of many birds.

In deeper (>5m) subtidal sub-Antarctic waters, the giant kelp *Macrocystis pyrifera* (Linnaeus) C.Agardh dominates and, like *D. antarctica*, performs important ecosystem-structuring services by providing habitat and food for many organisms. Pugh & Davenport (1997) hypothesised that *M. pyrifera* might survive some degree of ice scour as its holdfasts attach to the substrate deeply enough to avoid the ice foot. Molecular data, however, indicate that this species has probably recolonised many sub-Antarctic islands post-glacially (Macaya & Zuccarello 2010b), suggesting it does not survive long periods of sustained ice scour. Indeed, *Macrocystis* is not presently recorded from any of the islands within the northern limit of sea ice. More than a century ago, Skottsberg (1904) noted the absence of *Macrocystis* from the South Orkney Islands and suggested it was unlikely to occur near any islands within the northern limit of drifting sea ice (which he defined as the "Antarctic" zone).

Molecular studies of *D. antarctica* (Fraser *et al.* 2009), *M. pyrifera* (Macaya & Zuccarello 2010b), and some kelp-associated invertebrates (Nikula *et al.* 2010) indicate that most sub-Antarctic kelp communities have recolonised LGM sea ice-affected regions (fig. 1) post-glacially, presumably via rafting. Circumpolar dispersal would have been facilitated by the strong eastward-flowing Antarctic Circumpolar Current (ACC), also known as the West Wind Drift (Waters 2008). Tens of millions of detached *D. antarctica* are estimated to be drifting in the path of the ACC at any time (Smith 2002), and can carry associated invertebrate communities

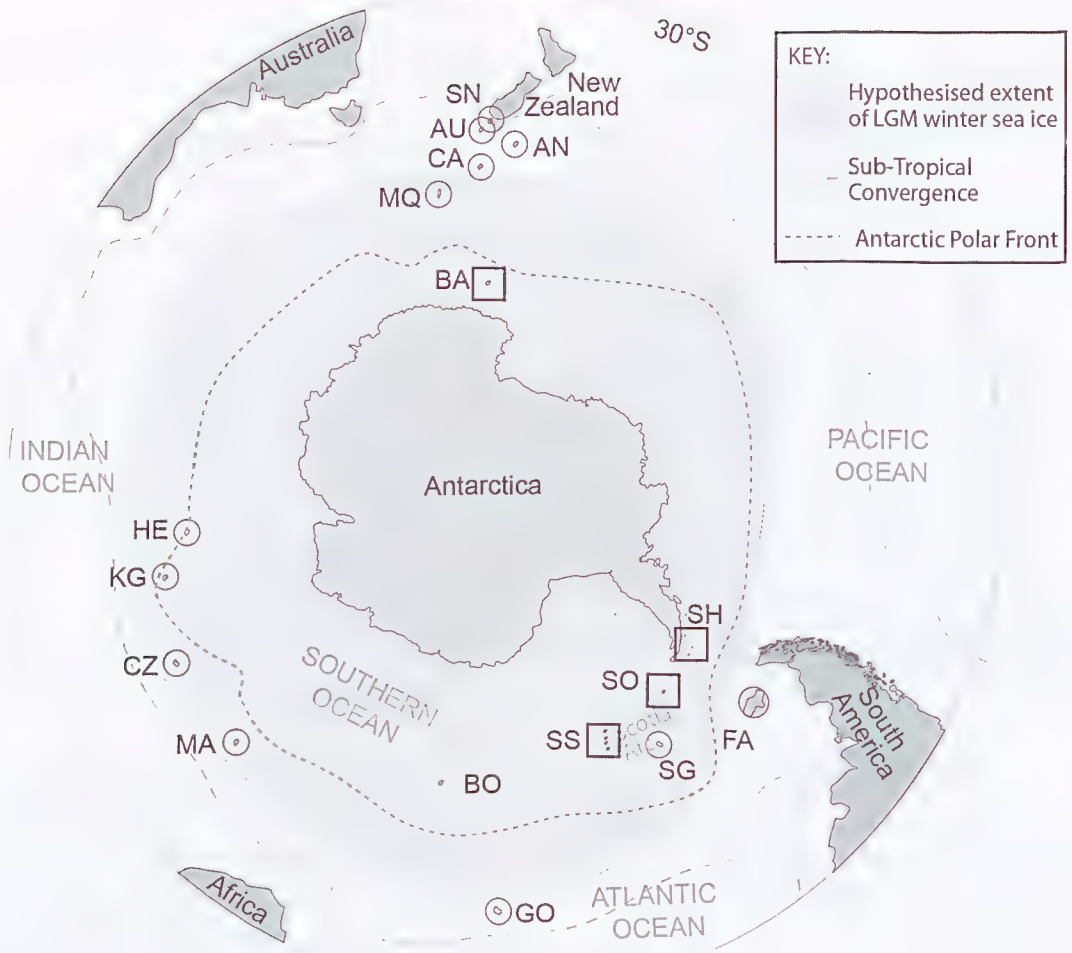

FIG. 1 — Map showing the locations of major sub-Antarctic and some Antarctic islands, with those indicated by circles not currently within the extent of Antarctic sea ice, and those indicated by squares within winter sea ice range. AN: Antipodes Islands; AU: Auckland Islands; BA: Balleny Island; BO: Bouvet Island; CA: Campbell Island; CZ: Crozet Islands; FA: Falkland Islands (also known as Malvinas); GO: Gough Island; HE: Heard Island; KG: Kerguelen Islands; MA: Marion and Prince Edward Islands; MQ: Macquarie Island; SG: South Georgia; SN: Snares Islands; SO: South Orkney Islands; SS: South Sandwich Islands; SH: South Shetland Islands. Note: not all islands within the region are shown.

long distances among isolated oceanic landmasses (Fraser *et al.* 2011). Post-glacial recolonisation of the sub-Antarctic by rafting would therefore have been possible even for some otherwise sedentary or poorly motile organisms. Based on molecular patterns, recolonisation by *D. antarctica* is inferred to have occurred from a refugium in the New Zealand sub-Antarctic (Fraser *et al.* 2009, Fraser *et al.* 2010a).

Not all intertidal and shallow subtidal organisms are likely to have been driven locally extinct at sub-Antarctic islands within the range of sea ice at the LGM. Some taxa are ice-resistant, able to survive at depths below the reach of scouring ice, or in shelters such as rock cracks (Barnes 1999), and these might have survived Quaternary ice ages *in situ* on the islands (Fraser *et al.* 2012). Thus, sub-Antarctic nearshore ecosystems could have cycled, with glacial–interglacial changes, between ecosystems structured largely by the ice-scour susceptible kelps *D. antarctica* and *M. pyrifera*, and more ice-resilient communities.

SUB-ANTARCTIC LITTORAL ECOSYSTEMS DURING GLACIAL MAXIMA

During Quaternary glacial maxima, when Antarctic sea ice is hypothesised to have – at least occasionally – extended far enough north to have affected Marion, Macquarie, Crozet, Kerguelen and Heard islands (Fraser *et al.* 2009, Fraser *et al.* 2012) (fig. 1), sub-Antarctic intertidal and shallow subtidal ecosystems might have been comparable to those found today at islands still within the reach of Antarctic winter sea ice, such as the South Shetland or South Orkney islands (pl. 2). There, sparse and relatively small macroalgae with short or biphasic/seasonal life cycles dominate the shallow marine floral assemblages, and hardy, motile invertebrates such as limpets and amphipods can persist despite frequent scouring of the rocky shores by ice. Mercier & Hamel (2005, p. 87) described the littoral flora and fauna of the Scotia Arc islands:

PLATE 1

Durvillaea antarctica *is an important ecosystem-structuring species in the sub-Antarctic. These photographs, from Marion Island in April 2007, show: (A)* D. antarctica *growing densely in the intertidal, as well as detached and cast up on the beach (Fur and Elephant seals indicate scale), and (B)* D. antarctica *and other macroalgae covering almost all available rocky substrate in the intertidal (scale represents approximately 20 cm) (Photos: Ceridwen Fraser).*

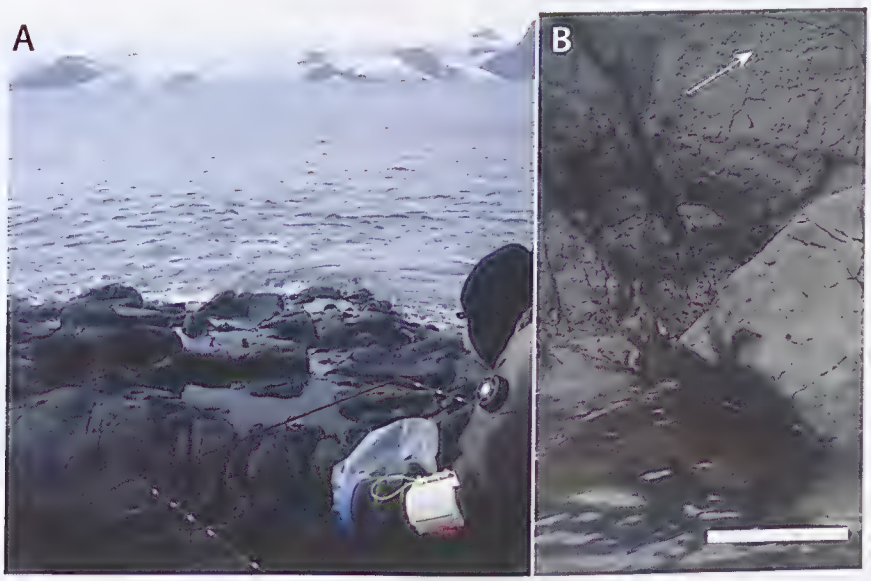

PLATE 2

At the peak of the last Ice Age, many sub-Antarctic littoral ecosystems probably resembled those of Antarctic islands currently within the reach of sea ice, such as the South Shetland Islands. These photographs, taken during intertidal surveys in the South Shetland Islands (King George Island) in February 2008, show ice-scoured rocky shores lacking the diverse macroalgal cover of sub-Antarctic islands. Some algae (see arrow in panel B) and motile fauna such as limpets can persist by sheltering in rock cracks and crevices. Scale in panel B represents approximately 40 cm (Photos: A: Carlos Olavarria; B: Emma Newcombe).

> *Overall, the biota of the intertidal region is poor... the midlittoral zone ... is characterized by the presence of the* Porphyra *algae ... there are also algae in the tide pools and crevices. Limpets ... occur in crevices, whereas amphipods, nemertines, and flatworms are found clustered under stones and rocks. The tide pools of the midlittoral are home to many Antarctic species of algae such as* Leptosomia, Iridaea, Adenocystis *that can also extend their distribution to the infralittoral fringe area with* Desmarestia, Curdiea, Monostroma, *and* Plocamium. *The infralittoral fringe is characterized by numerous algae, mainly of the genera* Desmarestia *and* Ascosiera. *The huge* Phyllogigas grandifolius [now *Himantothallus grandifolius*] *dominates this* [subtidal] *area ...*

On South Georgia, some littoral regions are scoured by ice breaking away from the island's glaciers, whereas other areas are rarely impacted by ice, providing an interesting system for studies of the impacts of ice scour. An ecological study on South Georgia by Pugh & Davenport (1997)

documented differences in these shallow marine ecosystems, and demonstrated that some macroalgae, such as *Porphyra* and *Urospora* species, survive in rock crevices in the ice scoured areas.

Many of the intertidal/shallow subtidal algae (e.g., *Desmarestia ligulata* (Stackhouse) J.V.Lamouroux, *Adenocystis utricularis* (Bory de Saint-Vincent) Skottsberg, *Bostrychia intricata* (Bory de Saint-Vincent) Montagne, several *Porphyra* species) of islands presently within Antarctic sea ice extent also occur on sub-Antarctic islands further north. Preliminary molecular data from *A. utricularis* and *B. intricata* – circumpolar macroalgae that occur throughout the sub-Antarctic, including on some currently ice-affected islands – indicate that these taxa do not show classic genetic signatures of post-glacial recolonisation of LGM ice-affected islands (Fraser, unpublished data). These species may therefore have persisted *in situ* throughout recent glacial maxima. Similarly, limpets of the genus *Nacella* show considerable phylogeographic diversity in the sub-Antarctic (González-Wevar *et al.* 2010), indicating that congeners have likely been scattered throughout the sub-Antarctic since well before the LGM. Sub-Antarctic littoral ecosystems during glacial periods therefore probably comprised a depauperate subset of modern-day sub-Antarctic taxa.

CONCLUSIONS AND IMPLICATIONS

Some of the dominant macroalgal species – and associated invertebrate communities – of the littoral ecosystems of many sub-Antarctic islands today were apparently extirpated from the islands during the last Ice Age (and presumably at previous Quaternary glacial maxima). When sea ice extended far enough north to scour sub-Antarctic shores, littoral ecosystems would have been drastically different, with diversity reduced to those species capable of surviving in ice-affected regions. Dispersal by rafting would have allowed recolonisation of the islands by ice-sensitive taxa during warmer interglacial periods.

Sub-Antarctic littoral ecosystems thus appear to have been able to recover from some of the impacts to biodiversity of Quaternary climate change cycles, but predicting the impacts of, and biological response to, future climate change in the region is not straightforward. Global average temperatures in coming decades are predicted to exceed any experienced during the Quaternary (I.P.C.C. 2007), and using pre-Quaternary warm periods as analogues of future climate change is complicated by uncertainties related to factors such as changes in oceanography, topography and continental positions (Haywood *et al.* 2011). Global warming is expected to lead to poleward range shifts for many taxa (Hickling *et al.* 2006), but southward dispersal of sub-Antarctic taxa would require traversal of oceanic barriers such as the Antarctic Polar Front (Fraser *et al.* 2012).

Fortunately, the sub-Antarctic is expected to experience slower rates of global warming than at similar latitudes in the Northern Hemisphere (Sandel *et al.* 2011), perhaps largely due to oceanic climate buffering. *D. antarctica* cannot tolerate high water temperatures (greater than about 17°C), and its northern limit is currently approximately in line with the limit of sub-Antarctic waters (although relatively sparse northern populations occur up to about 30–35°S in the cool-temperate waters of New Zealand and Chile) (Fraser *et al.* 2010b). The now monospecific genus *Macrocystis* has a slightly broader distribution in the Southern Hemisphere, ranging from the sub-Antarctic to cool-temperate latitudes (e.g., the southern coast of South Africa, southeastern Australia, and along the path of the Humboldt Current in South America) (Macaya & Zuccarello 2010a). If either species is extirpated from sub-Antarctic islands by warming ocean temperatures, significant changes to littoral (and, indirectly, terrestrial) ecosystems in the region are sure to result, but these changes will be unlike any the region has experienced during the past 2–3 million years.

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REFERENCES

Barnes, D.K.A. 1999: The influence of ice on polar nearshore benthos. *Journal of the Marine Biological Association of the United Kingdom*, **79**: 401–407.

Dufour, C. 2011: The influence of stranded kelp (*Durvillaea antarctica*) on the macrofaunal assemblages of a southern New Zealand exposed sandy beach. Unpubl. MSc thesis, University of Otago, Dunedin: 98. http://hal.handle.net/10523/1940

Edgar, G.J. & Burton, H.R. 2000: The biogeography of shallow-water macrofauna at Heard Island. *Papers and Proceedings of the Royal Society of Tasmania*, **133**: 23–26.

Fraser, C., Thiel, M., Spencer, H. & Waters, J. 2010a: Contemporary habitat discontinuity and historic glacial ice drive genetic divergence in Chilean kelp. *BMC Evolutionary Biology*, **10**: 203.

Fraser, C.I., Nikula, R., Ruzzante, D.E. & Waters, J.M. 2012: Poleward bound: biological impacts of Southern Hemisphere glaciation. *Trends in Ecology & Evolution* **27**: 462–471.

Fraser, C.I., Nikula, R., Spencer, H.G. & Waters, J.M. 2009: Kelp genes reveal effects of subantarctic sea ice during the Last Glacial Maximum. *Proceedings of the National Academy of Sciences, USA* **106**: 3249–3253.

Fraser, C.I., Nikula, R. & Waters, J.M. 2011: Oceanic rafting by a coastal community. *Proceedings of the Royal Society B: Biological Sciences* **278**: 649–655.

Fraser, C.I., Winter, D.J., Spencer, H.G. & Waters, J.M. 2010b: Multigene phylogeny of the southern bull-kelp genus *Durvillaea* (Phaeophyceae: Fucales). *Molecular Phylogenetics and Evolution* **57**: 1301–1311.

González-Wevar, C.A., Nakano, T., Canete, J.I. & Poulin, E. 2010: Molecular phylogeny and historical biogeography of *Nacella* (Patellogastropoda: Nacellidae) in the Southern Ocean. *Molecular Phylogenetics and Evolution* **56**: 115–124.

Haxen, P.G. & Grindley, J.R. 1985: *Durvillaea antarctica* production in relation to nutrient cycling at Marion Island. *In* Siegfried, W.R., Condy, P.R. & Laws, R.M. (eds): *Antarctic Nutrient Cycles and Food Webs.* Springer-Verlag, Berlin: 637–640.

Haywood, A.M., Ridgwell, A., Lunt, D.J., Hill, D.J., Pound, M.J., Dowsett, H.J., Dolan, A.M., Francis, J.E. & Williams, M. 2011: Are there pre-Quaternary geological analogues for a future greenhouse warming? *Philosophical Transactions of the Royal Society A: Mathematical, Physical*

and Engineering Sciences **369**: 933–956.

Hewitt, G. 2000: The genetic legacy of the Quaternary ice ages. *Nature* **405**: 907–913.

Hickling, R., Roy, D.B., Hill, J.K., Fox, R. & Thomas, C.D. 2006: The distributions of a wide range of taxonomic groups are expanding polewards. *Global Change Biology* **12**: 450–455.

I.P.C.C. 2007: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007.* Cambridge University Press, Cambridge, UK: 976 pp.

Kaehler, S., Pakhomov, E.A. & Mcquaid, C.D. 2000: Trophic structure of the marine food web at the Prince Edward Islands (Southern Ocean) determined by d13C and d15N analysis. *Marine Ecology Progress Series* **208**: 13–20.

Klemm, M.F. & Hallam, N.D. 1988: Standing crop of *Durvillaea antarctica* (Chamisso) Hariot (Phaeophyta) on the Australian sub-Antarctic Macquarie and Heard Islands. *Phycologia* **27**: 505–509.

Macaya, E.C. & Zuccarello, G.C. 2010a: DNA barcoding and genetic divergence in the Giant Kelp *Macrocystis* (Laminariales). *Journal of Phycology* **46**: 736–742.

Macaya, E.C. & Zuccarello, G.C. 2010b: Genetic structure of the giant kelp *Macrocystis pyrifera* along the southeastern Pacific. *Marine Ecology-Progress Series* **420**: 103–112.

Mercier, A. & Hamel, J.-F. 2005: Atlantic Ocean islands, coastal ecology. *In* Schwartz, M.L. (ed.): *Encyclopedia Of Coastal Science*. Springer, Dordrecht: 84–88.

Nikula, R., Fraser, C.I., Spencer, H.G. & Waters, J.M. 2010: Circumpolar dispersal by rafting in two subantarctic kelp-dwelling crustaceans. *Marine Ecology-Progress Series* **405**: 221–230.

Petit, J.R., Jouzel, J., Raynaud, D., Barkov, N., Barnola, J., Basile, I., Bender, M., Chappellaz, J. & Delaygue, G. 1999: Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. *Nature* **399**: 429–436.

Pugh, P.J.A. & Davenport, J. 1997: Colonisation vs. disturbance: The effects of sustained ice-scouring on intertidal communities. *Journal of Experimental Marine Biology and Ecology* **210**: 1–21.

Sandel, B., Arge, L., Dalsgaard, B., Davies, R.G., Gaston, K.J., Sutherland, W.J. & Svenning, J.-C. 2011: The influence of late Quaternary climate-change velocity on species endemism. *Science* **334**: 660–664.

Skottsberg, C. 1904: On the zonal distribution of South Atlantic and Antarctic vegetation. *The Geographical Journal* **24**: 655–663.

Smith, S.D.A. 2002: Kelp rafts in the Southern Ocean. *Global Ecology and Biogeography* **11**: 67–69.

Smith, S.D.A. & Simpson, R.D. 2002: Spatial variation in the community structure of intertidal habitats at Macquarie Island (sub-Antarctic). *Antarctic Science* **14**: 374–384.

Taylor, D.I. & Schiel, D.R. 2005: Self-replacement and community modification by the southern bull kelp *Durvillaea antarctica*. *Marine Ecology-Progress Series* **288**: 87–102.

Waters, J.M. 2008: Driven by the West Wind Drift? A synthesis of southern temperate marine biogeography, with new directions for dispersalism. *Journal of Biogeography* **35**: 417–427.

(accepted 4 September 2012)

BOOK REVIEW

by Michael Roe

A Tale of Ambition and Unrealised Hope: John Montagu and Sir John Franklin
by Craig Joel

Australian Scholarly Publishing, North Melbourne, 2011: 475 pp.
ISBN 9781 921509 5452.

The clash between Sir John Franklin, Lieutenant-Governor of Van Diemen's Land 1837–1843, and his ranking bureaucrat, Colonial Secretary John Montagu, has a long and distinguished historiography. Franklin himself began this story as, on his return to Britain, he wrote his *Narrative and Unrealised Hope. John Montagu and Sir John Franklin.* John West (*The History of Tasmania* 1852) was the most interesting of the nineteenth-century commentators, and concern deepened from the 1930s. Sir Ernest Clark, Governor 1933–1945, included this episode in his enthusiastic study of Tasmanian history. Meanwhile, the distinguished local scholar Joyce Eyre (Phillips) wrote a master's thesis at the University of Tasmania on the controversy. Kathleen Fitzpatrick, like Eyre in talent and style, could not but address the issue at length in *Sir John Franklin and Tasmania* (1949), her sympathies strong with Franklin. Near-simultaneously Edmund Morris Miller wrote a pertinent essay, duly published in *Pressmen and Governors* (1952); informed and balanced, it is surely the one significant omission from Joel's bibliography. Recent decades have seen such important historians as A.G.L. Shaw and Lloyd Robson write of the subject.

All that record is surpassed by *A Tale of Ambition and Unrealised Hope: John Montagu and Sir John Franklin.* This unusually long monograph is based on close reading of the voluminous primary sources. The story has enough drama to keep the reader's attention. Readers will be left in no doubt as to Joel's determination to get to the root of things; while there occasionally might have been more rigorous sub-editing, his prose is generally adequate. Footnotes are abundant, and (with appendices) often add yet more data. The downside of this situation is that the sheer detailed complexity of the story threatens to overwhelm analysis and clarity. True, there were many intricacies and puzzles entailed, but the historian's task is to transcend such problems. Joel strives mightily in this task and for the most part with success.

While the front cover of the books depicts Sir John, Montagu precedes him in the sub-title and is the dynamic element in the saga; both men had ambitions and unrealised hopes, but Montagu's were the stronger. A key and ultra-efficient figure in the regime of George Arthur (to whom he was related), he no doubt was wary of the new incumbent from the outset. However, the early months saw no great friction, even some amity. Tensions arose in early 1838, apropos one Clapperton, a clever convict cook, but also a miscreant; on consequent dismissal by his current employer and further sentence, Montagu intervened in hope of getting the man onto his own domestic staff. Franklin sent Clapperton up-country. The issue was made much of in the local press: Hobart had a remarkable variety of newspapers, strident in their antagonisms, the anti-Arthur/Montagu voice being loudest in this instance. While clearly in the wrong and suffering no overt rebuke from Franklin, the Secretary now wrote to Arthur as to his desire to leave VDL: "it is painful beyond description to act under a Governor who has no firmness of character, and is the tool of any rogue who will flatter his wife, for she in fact governs".

Yet civil relations continued between the two men, up to Montagu's sailing for Britain (on leave) soon afterwards. Holding that view of Franklin, he surely should have striven to get another posting. Instead, he established himself at the Colonial Office as adviser on Vandiemonian affairs. The Office was all the readier to listen as governmental policy, following the "Molesworth" Report (from a high-powered Parliamentary committee), declared assignment of convict labour to individual employers to be akin to slavery, and so demanding of abolition. Montagu blew with these winds of change. He affirmed that the Tasman Peninsula was capable of accommodating "any number" of convicts, there to undergo penal severity before going forth as labourers, first in the island's "unsettled" districts. He gave no hint of foreseeing difficulties likely to ensue from this "probation" system.

In March 1841 Montagu returned to Hobart. Economic times were relatively buoyant, and dominant opinion saw it as more boon than obliquity that the island should receive virtually all Britain's transported convicts, with their associated imperial spending. Franklin himself made no hard-headed analysis of troubles that "probation" might cause. Soon, however, as much-increased convict numbers arrived while the general economy worsened, those troubles became inexorable. Now, too, sharpened tensions between Montagu and the Franklins developed, in terms proposed by the former's letter to Arthur in early 1838. That Jane Franklin allegedly had an undue part in her husband's decisions took an ever-larger part in this grim business. One result was for a local newspaper, the *VDL Chronicle*, to abuse Sir John and his Lady. Montagu was close to the *Chronicle*'s editor, and Franklin charged him with complicity in the affair. Montagu subsequently alleged the Governor's power of mind and memory to be deficient.

Indeed, Franklin was vague and variable in discharging his role, while Jane had a sizeable role in governmental affairs.

One can well understand Montagu becoming frustrated. Yet these situations do not appear to have been extreme, and the task of subordinates is to obey. Montagu failed this test: his ambition prevailed. Conversely, an instance of the Governor's style was his having depended much on Montagu, but at the end turned abruptly upon him. On 25 January 1842 the Colonial Secretary was suspended from office.

He returned to London, determined to redeem himself and conceivably to win appointment as Franklin's successor. His situation was dangerous, George Arthur himself warning of need for care. Montagu continued to insist that VDL could receive loads of convicts. The Colonial Office was happy to hear that, but its treatment of Montagu was equivocal. He was not reinstated as Colonial Secretary, let alone considered as Franklin's successor, but did receive a post as Colonial Secretary at Cape Town. Moreover, Britain's Secretary of State for the Colonies, Lord Stanley, told Franklin that his suspension of Montagu was "not ... sufficiently vindicated".

That despatch arrived in Hobart in January 1843, much distressing its recipient. Through the months ahead Franklin expected notice of peremptory recall, and he and Jane dwelt on the "foul conspiracy" against them. However, a despatch signifying recall was not written until February 1843, arriving six months later, and instead of any further censure merely remarked that the normal gubernatorial term of six years had arrived. Joel makes the important point that several Australian governors received more severe treatment than this. That was to become desperately true of the next incumbent in VDL, Sir John Eardley Eardley-Wilmot. On him, as the final chapters of the book relate, fell the full, impossible task of managing "probation".

While not recalled in disgrace, the Franklins continued their outrage at Montagu and his works. Sir John first wrote the *Narrative and Unrealised Hope. John Montagu and Sir John Franklin*, and then resumed his (doomed) career as explorer. Joel suggests that silent dignity might have been a happier stance. This is an instance of his sensible judgment, his overall and well-argued sympathy for the Franklins having appropriate moderation. In a commendation of Joel's work, here quoted, the late Professor Shaw wrote that it is "not as unfair to Montagu as I think some of his critics have been in the past". "Who can tell where the truth lies?", Jane Franklin herself once wrote of the affair; "the same rectitude of sentiment is professed by both [sides]." She herself failed to maintain that insight, but Craig Joel does.

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Website:

IUCN 2001: *IUCN Red List of Threatened Species 2001 Categories & Criteria (version 3.1)*, www.iucnredlist.org (accessed 22 January 2007).

Report:

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